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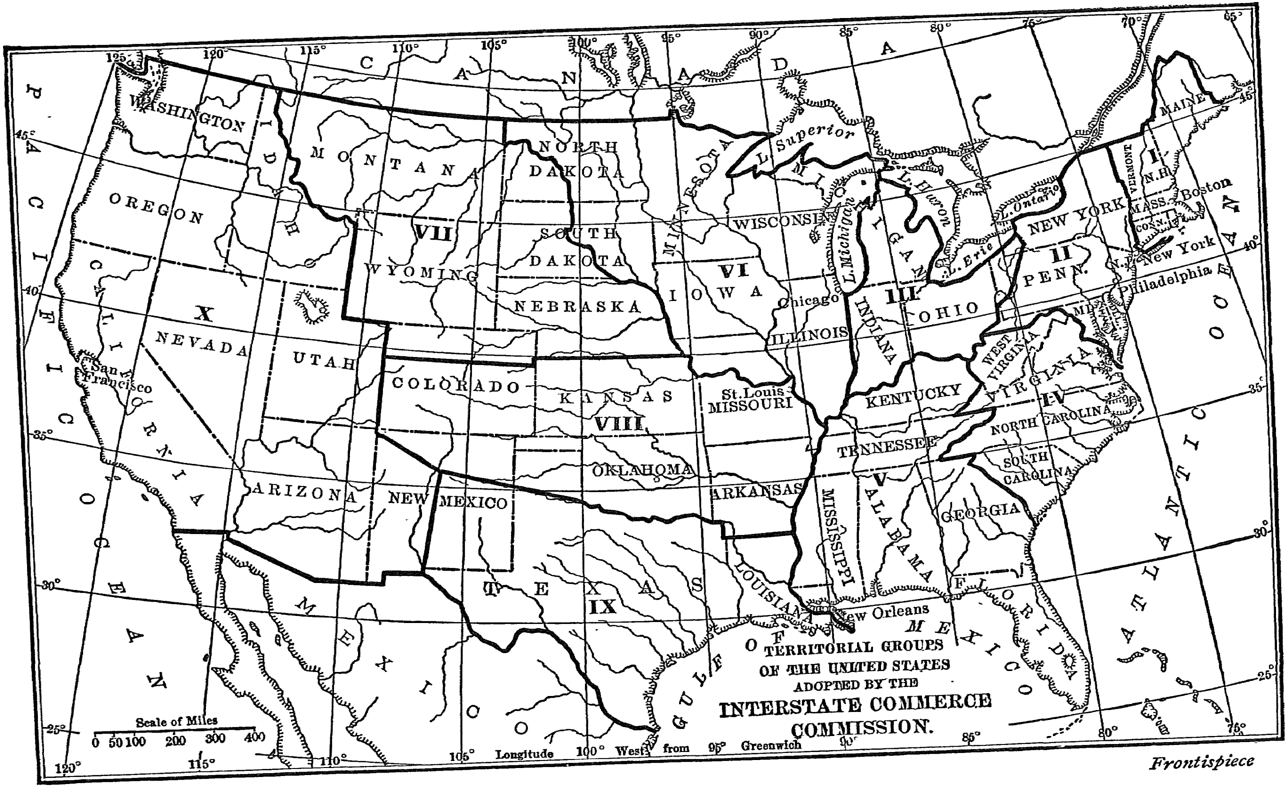

Frontispiece

THE ELEMENTS

OF

RAILROAD ENGINEERING

BY

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PREFACE

A RAILROAD with its rolling stock and buildings constitutes a manufacturing plant which its owners operate in the manufacture and sale of transportation. The "layout" or arrangement of a modern manufacturing plant is as much an item of design as is each individual machine or process. This book attempts to describe the fixed portion of a railroad plant and to give the underlying principles of the design of its layout.

A policy adopted in the preparation of the book has been to treat briefly and generally those subjects which are fully and well covered in special volumes, to which the student is referred, and to go into detail in those subjects treated only in books of the same class as this one.

An effort has been made to indicate at least indirectly that there are other methods of doing things than those presented, and to lead the student or reader to think of other possible ways than those described in the book.

The plan of first describing the thing and then discussing its design, has been followed. Part I describes the permanent way in as much detail as has been thought wise; Part II discusses the fundamental principles governing the design of the grade line, while Part III describes the methods of applying these principles to secure the most economical location and construction. Part III also contains many suggestions which would have been most welcome to the author when he was placed in charge of his first residency.

Not much space has been given to diagrams for the discussion of locomotive and grade problems, but the author uses diagrams and believes in diagramming almost all formulas for a thorough study of the effect of variations in the variables, and

he suggests to instructors using this book for class work that they give not a little time to graphical representation of the principles of Part II. Additional examples for the application of these principles may be formulated from the data appearing on Plates I to XI inclusive.

The author has tried to use few words, and to have all of them mean something, in the desire to condense into proper proportion for a broad civil engineering course almost all of the fundamental principles of a great subject, which may be amplified as much as desired by those using the book.

The wisdom of including so long an appendix as appears may be questioned. The author has felt that the value to the young engineer of Professor Taylor's paper and the discussion on it, even though some of the principles discussed in the text are repeated, is great enough to warrant the appearance of almost the whole matter. Nothing is more effective in fixing principles than a well-discussed example from practice, and the variety of viewpoints and suggestions in this discussion will furnish many ideas to the student reader.

In addition to what has been said of the scheme of the book as a whole, it may be proper to call attention to some particular features or portions.

It is hoped that the sequence of arrangement and the method of treatment may commend themselves to the student and teacher. In the introduction there are presented briefly, and far from completely, what are thought to be rational ideas of railroad political economy. The paragraph on the comparative worth of cross-ties is thought to be sound and to furnish correct principles for economic investigations in other directions. It is hoped that the brief discussion of the locomotive as a traction engine will be found valuable, and that the articles on curve resistance and the cost of the worst class of rise and fall, which are original, will be found correct. The article on reconnaissance estimates, and that on the work of the residency, will perhaps be of service to young engineers on their first work.

The author is indebted to Mr. Ray Morris for criticism of

portions of the introduction and to the following for permission to use cuts or matter: To the *Railroad Gazette* and Mr. B. B. Adams for cuts from the *Railroad Gazette* and from *The Block System;* to the Ramapo Iron Works for cuts of frogs and switches; to *Engineering News* for cuts from that journal and from Tratman's *Track;* to Mr. G. W. Kittredge, Chief Engineer of the New York Central and Hudson River Railroad, for numerous standard plans; to the Hall Signal Company for the electrotype for Plate (p. 114); to the American Locomotive Company and the Baldwin Locomotive Works for electrotypes of locomotives for Plates I to XII. Other indebtednesses are noted in the text.

Every author of a text-book treating of the economics of railroad location must of necessity be indebted in great measure to the late A. M. Wellington, and the author of this book wishes to acknowledge this indebtedness and to express his admiration for the man who has done more than any American, if not more than any man, to raise railroad location from a trade to a profession.

WILLIAM G. RAYMOND.

IOWA CITY, IOWA, January, 1908.

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ELEMENTS OF RAILROAD ENGINEERING

INTRODUCTION

Inception of a Railroad Enterprise. — Railroads in America are built for a single avowed purpose; namely, to make money for the projectors.

These projectors have various ideas as to how the money is to be made. In one case — perhaps the majority of cases — they expect to make a sufficient profit on the business of general transportation to pay a fair return on the money invested in the road. In another case they expect to make money by the sale of lands owned by them. The road is built to or through these lands from some important commercial center, in order to make the lands accessible and hence to bring them into market at a price sufficient to yield a profit on the cost of the lands and the cost of the road. In another case the road may be projected by a company of men owning coal, iron, or other mines, for the purpose of getting the output of the mines to the nearest or best market at a minimum cost. In this case the road may be built if the estimated difference between the cost of transportation by rail and the cost by wagon or other available method is sufficient to pay interest on the cost of the road and equipment. In another case a company of men owning and operating a railroad conceive that an extension of the line into new territory, or the building of a lateral branch to some commercial or agricultural district, will, whether it will be remunerative in itself or not, bring such an added volume to the business of the existing road, which additional volume of business can be conducted without much additional expense, that

the net result of the loss, if any, from the branch itself and the gain to the main line will be sufficient to yield a fair return on the cost of the new line.

In other cases — fortunately comparatively few — a road is projected and, sometimes, when the funds can be secured, actually built, for the purpose of blackmail. That is, some vicious-minded person, noting that an existing road is doing a handsome business and making a similar profit, conceives the idea that its owners will be so anxious that their business shall not be interfered with, that they will be glad to offer to any other company proposing to build a parallel line a substantial bonus to keep off; and that if these owners do not make such an offer, the parallel line may be built and rates reduced so as to damage the existing company to an extent that will bring it to terms and compel it to buy the new road in self-defense. Such projects have not usually been successful.

Formation of Company. — In any case, if the road is to be a new one, independent of any existing organization, the order of procedure may be somewhat as follows: —

The person who conceives the idea of the road associates with himself other persons whom he may be able to impress with the feasibility of his scheme, and they organize themselves into a company or corporation by filing with the State authorities articles of incorporation which set forth the purpose of the corporation, the amount of capital stock that it is proposed to issue, the names of the first board of directors, the extent and location of the proposed line, and some other items, varying according to the requirements of the State in which the company is organized.

It is not unusual for a company to be organized under the laws of a State in which no one of the individuals forming the company lives and within which no part of the proposed line lies. This is done because of some provision of the laws of that State that the organizers think particularly favorable to them.

Formerly a special enactment of the legislature was necessary to give a company power to condemn land for its purposes. Now in most States, if not in all, this power is conferred by general laws to companies organized under those laws.

The right to build and operate a road is known as a franchise or charter, and that is what the company secures from the State. It carries with it the right to take such lands as may be needed for the purposes of the road, the company to pay for such lands a fair value. This value may be arranged by agreement between the company and the owners of the land taken, or, in case they are unable to agree, the value of the land is settled by a court, through a commission. If condemned by a commission, the company is estopped from ever using the property for any other than the avowed purpose for which it was acquired, while if the fee is obtained by deed, the company is not so limited.

Stock. — A certificate of stock is a paper certifying that the person in whose name it is made out owns a stated interest in the capital stock of the company issuing the certificate, and such a certificate constitutes evidence of membership in "the company." From the bookkeeper's standpoint the company is indebted to the holders of stock in the amount of their holdings, and to this extent stock and bonds are of the same nature; but bonds bear a definite rate of interest, while stock takes what it can get in dividends.

The persons forming the company agree to take each a certain amount of the capital stock of the company. Persons whose subscriptions for stock are accepted, thereby become stockholders in the company. The company is a legal entity that does business just as an individual, except that it does it through others, who are known as its officers. It is usual for each stockholder to have one vote in the affairs of the company for each share of stock owned or held by him.

The stockholders usually elect a board of managers, known as the directors, and this board of directors elects the general officers of the company, sometimes partly from its own membership. The board of directors determines all matters of general policy, not requiring action by the stockholders, and the officers execute its orders, being responsible for the detail of the operations undertaken. This is the theory. In practice the board of

directors often becomes simply the endorser of the acts of its executive committee or the president of the company.

In many, but not all States, the company does not exist in law, even though its articles have been filed, until a specified portion of the capital stock has been subscribed and paid for in cash. The portion not subscribed by the originators of the scheme may go into the treasury of the company to be sold for funds with which to build. While held by the company it is known as treasury stock.

It is not necessary, nor usual, when a new company is being organized, for the subscribers to the capital stock to pay in full the par value of the stock subscribed for; indeed, it is more usual for these first subscribers to pay very little for their stock. The company hopes to borrow enough money to build and equip the road, and the amount paid by the subscribers to the stock will usually be the difference between the cost of the road and equipment and the sum the company is able to borrow. It will frequently be not more than enough to pay the cost of the preliminary surveys necessary to furnish information as to the probable approximate cost of the road. It is sometimes not so much as this, and sometimes nothing at all beyond the legal requirement, and often ways are found of evading even this. When the money for construction is borrowed, the company executes a mortgage covering usually the franchise and entire property.

Bonds. — Bonds, which, like notes, are promises to pay, and which refer to the mortgage as security, are issued, usually in $1000 units, in the amount of the mortgage, and the lenders of money receiving these bonds are said to be purchasers of bonds.

These bonds are of two general classes, — registered bonds and coupon bonds. The ownership of the former is kept track of by the trustee or company; and when a bond is sold by one person to another, the change of ownership is registered, so that the interest, when it falls due, may be sent to the right owner. It is usually sent by check. The coupon bonds have coupons attached to them, each coupon being a draft on the company for a stated

portion of interest falling due at a stated time. Whoever owns such a bond simply clips off each coupon as it falls due and deposits it in his bank for collection. The principal of a coupon bond may be registered, but not the coupons, which are payable to bearer.

If the projectors of the line have faith that it will be able to earn at least the interest on its first cost, and if they be men of means, they may supply the whole of the money necessary to build and equip the line. In this case they do not buy the capital stock of the company, paying into the treasury therefor its par value, but they lend the necessary money to the company; that is, they buy its bonds, receiving as a bonus a certain portion of stock, — usually an amount equaling at its par value the par value of the bonds taken. If the projectors are not men of means, they endeavor to persuade capitalists to lend the necessary money, and to do this for the bonds (usually sold for somewhat less than par value) and so small a stock bonus as can be arranged. The company must be able to convince the capitalists that the business the road will be able to do will, under fair management, which must be supposed, at least pay all operating expenses, including repairs and renewals, and the proposed interest on the bonds to be issued. To this end an estimate of the cost of constructing and equipping the road, and an estimate of the probable cost of operation and revenue, must be made.

Railroad loans are not made on the basis of the actual road-bed and rolling stock as security, though of course these items have some small inherent value; but the security is the business the road may be able to do, or may be made to do, under proper management. This fact explains why it is often possible to borrow the whole actual cost of the road and equipment, rather than one half or other small fraction of its estimated value, as would be the case with a dwelling or other real estate.

The stock and bonds together constitute the capitalization of the company, the bonds having precedence in the distribution of the earnings up to the amount of their interest rate. What is called preferred stock is sometimes issued, which, after the bonds,

takes precedence of the common stock in the distribution of earnings up to a specified dividend rate.

Engineer's Estimates. — The cost of construction and equipment is usually estimated by an engineer, after a reconnaissance survey, or a preliminary survey, of the proposed route. The estimate of probable cost of operation and revenue may also be made by him, but is more usually made by some of the promoters of the plan. A competent engineer should be able to make all the estimates. If the promoters endeavor to borrow money, that is, float their bonds, through some well-known trust company or banking house, such company or house may have its consulting engineer go over the estimates submitted, in order to satisfy itself that they are reasonably correct.

If the engineer who is employed to make a preliminary estimate makes it from a reconnaissance only, his work consists in going over the territory between the selected termini or principal points, on foot or horseback, and estimating, from his knowledge of what other lines more or less similarly located have cost, what this line, along a route that he selects, will probably cost. The estimate should include the road-bed, track, bridges, side tracks, water stations, buildings of all kinds, and rolling stock. In order to estimate the necessary rolling stock, he must have some rough idea of the business to be done, which he gets from observing the character of the country, the population and nature of industries, with possibilities for development, and comparing these features with those of some existing line or lines having as nearly as may be similar tributary territory. He finds the business done by the existing line or lines, and the rolling stock required, from the annual reports of these lines, a synopsis of which, often enough for his purpose, is furnished in Poor's "Manual of Railroads," or in the reports of the State Railroad Commissioners, or the statistical reports of the Interstate Commerce Commission. His estimate is, of course, only roughly approximate.

If he makes a preliminary survey, he actually lays out a line, after having determined by a reconnaissance which of several possible routes is the best, takes levels along the line and con-

structs a profile. On this he draws a grade line, from which he computes the probable quantities of excavation and embankment, the lengths and weights of iron bridges, the amount of timber for timber bridges, the masonry, etc., and hence is able to make a much closer estimate of the probable cost of the road-bed to sub-grade — that is, under the ties or sleepers — than he is able to make by reconnaissance only. He also gains a more exact knowledge of the rate of grade that must be used, and hence is better able to estimate the operating expense, since this is much affected by the rate of grade.

Construction. — If the estimates prove satisfactory, there will probably be little difficulty in floating the bonds; and when these have been subscribed for, the work of final location and construction may begin.

The bonds bear interest from the date of issue and delivery, and it is sometimes provided that the money will be advanced to the company only so fast as the engineer and president shall certify to the completion of work.

Whether or not the whole issue is drawing interest, it is invariably wise to build as rapidly as possible, that the interest on non-productive capital shall be as small as possible, and that as soon as may be the road shall begin to earn something. If it can be so arranged, it is usually best to open any completed portion of the road, provided the business of the completed portion will warrant the running of trains, without waiting for the completion of the whole line.

The road may be built by contract, or by day labor under charge of the engineer or a superintendent. The contract method is usually the better. The chief engineer will have entire charge of the work of construction, and will, with the assistance of the attorney for the company, and after consultation with the president, draw all specifications and contracts for the work.

Operation. — On the completion of the road the chief engineer is usually assigned the control of road-bed, track, bridges, and buildings, while a chief of motive power, or master mechanic, is assigned control of the construction, or purchase, and mainte-

nance of the rolling stock. Both of these officers report to and are under a general manager, the general superintendent, or the president. Usually the general superintendent has charge of the movement of trains and the handling of business. The organization varies in the different companies according to the magnitude of the enterprise and the ideas of the management, — that is, the president and board of directors.

The freight agent attends to the securing and forwarding of freight business. The passenger agent likewise attends to securing and forwarding passenger business. Both of these officers make known their wants as to trains to the officer in charge of the movement of trains — usually the general superintendent.

There may be a superintendent, or engineer, of bridges and buildings, and a general road master, the latter in charge of track, both reporting to the chief engineer or general manager or other officer according to the organization. Both of these officers should be under the chief engineer.

The road is operated by these various officers and their assistants, presumably to the best advantage as they see it, the president usually being responsible for matters of general policy, and all such matters must be referred to him. He will know what he can order and what he must refer to his board of directors.

Railroad Failure. — If the company fails to pay the interest on its bonds, as it falls due, foreclosure proceedings may be instituted, and the road sold to the highest bidder, usually some one representing the bondholders, who will then form a new company for the operation of the road. In point of fact a company is usually formed before the sale and is probably the only bidder. Foreclosure proceedings are usually taken only by request of a majority or large number of the bondholders. Moreover such action is generally avoided by the appointment of a receiver on the request of some bondholder or bondholders. A receiver is an officer of the court, appointed to take charge of the road and operate it pending some arrangement that may be made by company and bondholders, looking to a reorganization of the company on a new financial basis. Sometimes the receiver is able to bring the

road back to a paying basis, when it may be returned to the original company. Again, when no arrangement is arrived at, he may sell the road by order of the court, the bondholders usually buying it in at foreclosure sale.

There are several reasons for the failure of a railroad company, any one or more of which may cause the downfall. At least two of these are chargeable in great measure — frequently wholly — to the engineer.

1. The whole enterprise is an unwise one, there being no need of the road in the locality where it is; that is, all the business the locality can furnish at any possible rate will not pay the cost of operation, to say nothing of interest on the invested capital.

2. Poor location; that is, the line is so located as to reach such business as there is at a great disadvantage, thereby discouraging business, or it is located with too heavy grades and too sharp curvature to permit of economical operation. This cause usually operates only in cases where there is sharp competition.

3. Poor construction — costing so much for repairs and renewals and for operation as well, that no profit results. This is not so serious a difficulty as the second.

4. Bad management in operation.

5. Dishonorable financiering intended or tending to wreck the company to the profit of the financier.

6. Bad management in financiering, such as unduly increasing the bonded indebtedness, or overcapitalization. This is sometimes done with dishonest intent, and sometimes honestly by charging to capital account and borrowing money on improvements that are really but renewals which add nothing to the cash value, or earning capacity, of the road.

Overcapitalization. — It is a most fatal mistake to load a corporation with a fictitious capital in this way — and one of the most troublesome distinctions the management has to make is that between expenditures for capital and for legitimate operating expenses. Let it be supposed that a company owns five hundred freight cars, two hundred of which are so nearly worn out that they must be scrapped, and that the company is really in need of

more cars than the five hundred. It may buy three hundred new cars and charge the cost of the three hundred cars to capital, while it seems clear at once that the cost of two hundred should be charged to renewals, a legitimate operating expense. If the new cars are of larger capacity, or of better form, than the old ones, permitting by their use a reduction in operating expense, a portion of the cost may perhaps be said to belong to capital, and the scrapped cars have a small value as scrap; but such fine distinctions should not be made.

Again, if rails are worn out and replaced, no part of this item belongs to capital, but to operating expense, unless, indeed, the new rails are heavier and conducive to reduced cost of operation, when some indeterminate portion of their cost may fairly be placed to new capital; but, again, this distinction is not in accordance with a wise and conservative policy.

When it has become evident by reduced expenses and increased dividends that several such items have increased the value of the property, it will be possible to increase the capital stock to cover this increased value. Bonded indebtedness should not be increased for this purpose.

Stock Watering. — Increasing the stock in this way is sometimes known as stock watering, and the legitimacy of the practice is often questioned. One reason for it is to hide large dividends from the public, which usually demands that owners of public utilities shall receive only what is deemed a fair return on their actual investment. On the other hand, the cost of reducing the grades throughout the line, so as to permit the handling of longer trains and consequently fewer of them, thus materially reducing the expense of operation and increasing the value of the property, is legitimately a charge on capital, and it is right to increase the capital account to pay for it, although the more conservative companies do not charge such work as this to the capital account, but to operating expense. Such conservatism is doubtless to be commended, and it is notable that the owners of the road most prominently before the public in the pursuance of this policy in recent years suffered less than those of almost any other road

during the panic of 1893 and the following years. If new stock is issued to cover simply increased value due to previous betterments charged to operating expense, such stock should be distributed gratis and *pro rata* among the stockholders.

Railroad Valuation. — The valuation of a railroad property is one of the most difficult tasks coming to an engineer. The valuation may be for one of several purposes: —

1. To determine the price of purchase or sale.
2. To determine the proper distribution of joint expenditures or receipts of two or more companies, or their relative rights in joint properties.
3. To determine the allowable capitalization in those States controlling this matter.
4. To determine proper traffic rates.
5. To determine a value for taxation.

There may be two general bases for valuation: —

1. The value of the physical property without reference to its earning capacity.
2. The value of the property and business as a "going concern."

It is advanced that the first basis is the correct one to use in cases 2 and 3 above, and that the second basis is properly used in cases 1 and 5. Proper traffic rates have no relation to valuation except that the minimum net income should be at least sufficient to pay interest on the physical valuation.

The value of a property as a going concern must include the value of its physical property, which may or may not be at any given time in good condition.

The present value of the physical property is the actual cost of construction, including that portion of renewals that has added to the value of the property, as heavier rails, rolling stock and bridges, signaling equipment, etc., plus the probable cost of the right of way if the road were to be built now, and the present value

of land and buildings other than right of way, less the depreciation of present track and equipment since its construction or purchase.

For existing roads it is practically impossible to determine the original cost and the additions to value that have been made from time to time, hence the present value of the physical property of an existing road is determined by estimating the cost of reproducing the road-bed, structures, and equipment, with the necessary right of way, adding the value of land and buildings other than the right of way, and deducting the depreciation of the present track and equipment since its construction or purchase.

It is submitted that where taxation is based on physical value, the probable cost of right of way, which must include real and imaginary damages, should not be used, but rather the value of that right of way based on the value of adjacent property. For ascertaining a proper capital value, the probable actual cost of the right of way should be used. That cost is likely to be from two to four or more times the value of adjoining land. The difference will not be great in new, wild country of little value, and it may be considerable in thickly settled territory already well served by existing railroads.

The value of a railroad property as a going concern is the value of its net earnings capitalized at some assumed proper interest rate. The net earnings are the gross earnings less the following items: —

1. Maintenance of way and structures, including a sinking fund for renewals.
2. Maintenance of equipment, including a sinking fund for renewals.
3. Conducting transportation.
4. General expenses.
5. Taxes.
6. Rentals.

Whether or not the sinking funds mentioned should be included depends on the length of time taken for averaging income and expense and what renewals charged to expense of maintenance

have been made within the period. It is necessary to make an examination of the physical property to determine within what time renewals of its various parts must be made in order to determine the sinking fund allowance. This may be so large in the case of some items needing renewal at once, that for these items, after deducting a normal sinking fund allowance, a gross sum equal to the cost of the immediate renewals should be deducted from the final capitalized value of the net income.

The resulting value should represent the gross allowable capital, all of which is considered as a debt, the "company" being responsible to the individual bondholders and stockholders alike for the face value of the bonds and shares held. The purchase value of the property would be this gross capital less the bonded indebtedness.

If the bonds are drawing a higher rate of interest than that assumed in the determination of the value of the property, due allowance must be made in determining the purchase value, by subtracting from the gross capital a sum obtained by capitalizing the actual annual interest charge at the rate assumed in determining the gross capital value.

The difference between the value of the physical property and the capitalized earning value may be called the value of the franchise or charter. This may in some few cases be a negative quantity due to excessive cost of a line that would bear only moderate cost, to moderate cost for a line for which there was no need, to poor management of the property, or to such poor location that successful operation in competition with strong rivals is impossible. The details of valuation are too numerous to warrant discussion in this text.

In determining a value for taxation, the taxes cannot be first deducted from the gross income because they are not known, but the gross income less all deductions except taxes should be capitalized at a rate found by adding the interest rate and the tax rate.

This rule is based on the theory that what is known as personal property as well as real property is taxable, and that such taxes,

for convenience and certainty of collection, should be assessed against the corporation rather than against the individual holders of its bonds and stocks.

It is not the purpose of this book to discuss theories of taxation, and the subject, though an interesting one, will not be pursued further.

The Railroad and the Public. — The railroad, with some marked differences, is of the nature of a toll road, and for it the State exercises its right of eminent domain, — the right to take private property, for reasonable compensation, against the will of the owner. The railroad is always to some extent a monopoly. The State, therefore, is entitled to control the railroad in some degree, and has assumed to control the amount of its capitalization, the safety and efficiency of its service, the reasonableness of its tariff rates, and the equity of its dealings with its numerous patrons, insisting that there shall always be on any one road equal rates and efficiency of service for all business offered under like conditions.

Texas was the first State to completely control capitalization. The control of interstate roads by the federal government, while undoubtedly wise, hangs on a very slender thread of interpretation of a clause in the Constitution giving Congress the control of interstate commerce, — a clause that was formulated before railroads were thought of.

New York and Michigan have enacted (1907) what are perhaps the most comprehensive and wisest laws controlling corporations that have been enacted by any of the States. It should be remarked that in such laws especially the wisdom and fairness of the execution is of the first importance.

It is essential that the issuance of capital stock and bonds be controlled in order that railroad securities may be given stability and the innocent purchaser of these securities protected from the selfish or dishonorable, if not illegal, acts of powerful financial manipulators who have been guilty of diverting to their own pockets money that most right-thinking people believe belongs to the stockholders of the manipulated properties, in the

shape of either cash dividends or improvements in the physical property.

It is essential for the public good that railroad service be safe, and maintained at the highest possible plane of efficiency consistent with the magnitude of the business. It is a fact that railroad service in America is reasonably efficient, but it is not reasonably safe. Much more attention should be given to this item of control than to the item of maximum rates, which should in general be left to take care of themselves; but equal rates for equal service to all patrons should be jealously guarded that the business rights, privileges, and *natural advantages*, of persons and communities may be conserved.

The railroads, and all other corporations enjoying the semi or wholly monopolistic advantages of a public franchise, must be controlled for their own protection — that is, protection of their stockholders — by the State; but they should be protected also from hasty, ill-considered legislation that tends to increase their expenses, or diminish their income or profits. Legislation affecting these items should be had only after the fullest investigation of an honest and competent commission.

It is generally assumed by the public that only a fair return on the capital actually invested should be earned by public corporations enjoying franchises. This is doubtless true, but it remains to be determined what such a fair return may be. In one State at least it has been fixed at 8 per cent. It must certainly be more than can be realized from a savings bank or a government bond, else no one will put his time or energy into the development of the business. It is asserted with some positiveness that a fair return should not be measured by the capital actually invested, but in a large degree by the volume of business done. Some bank stock — and, indeed, some railroad stock — is worth many times its par value because of the magnitude of the business done on a small capital. There is no reason why the wise and energetic management of a railroad property, so long as its rates are just and reasonable, and its service safe and efficient, should not profit in some measure in proportion to the magnitude of the

business it does; and, indeed, there is good reason why it should so profit in the incentive that is thus given to increase the efficiency and extent of the business, which means added prosperity to the whole territory which it serves.

The cost of service, the magnitude of the business, the ability of the traffic to pay, and the freedom with which it moves, are all factors to be considered with the invested capital in determining the just and reasonable rate for service and a just and reasonable return on the invested capital.

The consideration of this great subject in detail, like the matter of taxation, is foreign to the purpose of this book, and the author contents himself with the announcement of the foregoing principles for the consideration of the student reader.

The Engineer's Duty. — Short branch lines excepted, it is very rare that a railroad, once built, is abandoned; for it is very rare that one is built that will not pay at least the operating expenses and a little over, though perhaps not enough to pay interest on its original cost. The road that will do just this, however, causes a loss to its original owners, who usually have to surrender it, with whatever they have put into it, to the bondholders, who then operate it for what they can get out of it.

It is the business of the engineer, therefore, to locate and build the cheapest line that will safely carry the expected traffic, increasing the expenditure beyond what is necessary to do this only when it can be clearly shown that the increased expenditure will be profitable in itself, and not even doing this if the increased expenditure will endanger the successful completion of the whole line, including equipment and a more or less extended period of unprofitable operation. If the company can secure all the money needed, then he is to leave no improvement in his line unmade that he can conclusively show to be a profitable improvement. Wide road-bed, heavy ballast and track, and permanent, heavy masonry and bridges are built for an assured traffic that will pay the interest on such construction, but they are not warranted for a road of probably thin traffic. The traffic will determine the advisable expenditure for light grades and easy curvature.

PART I

PERMANENT WAY

AMERICAN railroad permanent way is made up of steel T rails about 33 feet long, joined together with one of several forms of joint bars, and fastened by spikes to wooden cross-ties or sleepers bedded in a ballast of earth, cinders, gravel, or broken stone, resting on a road-bed made by grading up the hollows and grading down the hills in the line of the road, and such culverts and bridge structures as are necessary for stream crossing and drainage.

Railroads are standard gauge, broad gauge, or narrow gauge. The gauge is the cross distance between the inside of rail heads. Standard gauge is 4 feet 8½ inches. There are very few broad gauge roads. There are a good many narrow gauge roads, mostly in Europe, South America, and Asia. The commonest narrow gauges are 3 feet in North America and 1 meter in other countries.

Reference books for Part I are: Camp's "Notes on Track," Tratman's "Railway Track and Trackwork," Foster's "Treatise on Wooden Trestle Bridges," and Berg's "Buildings and Structures of American Railroads."

CHAPTER I

ALIGNMENT

Horizontal Alignment. — The horizontal alignment of the center line of a railroad consists of straight lines called tangents, connected by curves to which the straight lines are tangent. A railroad line is considered to increase in length with the direction in which it is originally located. Proceeding in this direction, the beginning of a curve is called the point of curve, abbreviated, P.C., and the end of a curve is called the point of tangent, abbreviated, P.T. The curves are arcs of circles usually flattened at the ends into what are called easement curves or transition curves. Easement curves are usually some form of spiral, the many different methods of laying these out always resulting in essentially the same curve. A former method, still in limited use, of easing the passage between tangent and curve, connects the main curve with the tangent by a short arc of a circle of greater radius than that of the main curve. Such a combination of main curve and two arcs of greater radius is known as a three-center compound curve. If a main curve consists of an arc of one radius only, it is called a simple curve; if of two or more arcs of different radii, a compound curve. Curves are known by their "degrees." The degree of a curve is the angle subtended by a chord of 100 feet. If such a chord subtends 4 degrees at the center of the circle of which the curve is a part, the curve is a 4-degree curve. In a three-center compound curve the end arcs are usually about half the degree of the main curve, but may be arcs of 0-degree 30-minute curves or 1-degree curves regardless of the degree of the main portion.

The point of junction of two arcs of different radii is known as the point of compound curve, abbreviated, P.C.C. At this point the two arcs have a common tangent, their radii lie in the same line. If a spiral easement curve is used, its beginning may be

called the point of spiral, abbreviated, P.S.; its end or junction with the main curve, the point of spiral-curve, P.S.C.; the junction of main curve and closing spiral, point of curve-spiral, P.C.S., and final end of spiral, P.S.T. In any spiral the degree of curve at any point of the spiral is proportional to the distance from the P.S.; it is always 0-degree at the P.S., and increases uniformly to the degree of the main curve it joins. But little used in 1880, the spiral is now used on almost all American roads.

The radius of a 1-degree curve is 5729.65 feet. The radius of any curve of degree D is found from the common expression for the length of a chord subtending a given angle. The length C of a chord subtending an angle of D degrees in a circle of radius R is given by $C = R \times 2 \sin \frac{1}{2} D$. If C be 100 feet, then $R = \dfrac{50}{\sin \frac{1}{2} D}$. Since for small angles the sine may be said to vary with the angle, the radii of small degree curves will vary approximately inversely as their degrees. Indeed, if the degree were the angle subtended by an arc of 100 feet instead of a chord of 100 feet, the radii would be exactly inversely as the degree. For ready approximate computations the radius of a 1-degree curve is assumed to be 5730 feet, and that of a D-degree curve $\dfrac{5730}{D}$. A 1-degree curve is relatively a flat curve; a 10-degree curve is relatively a sharp curve; 12- to 18-degree curves are infrequently found in the mountain districts of the eastern United States, 24-degree curves in the Rocky Mountains, 40-degree curves in some railroad yards, and a 50-foot radius is the smallest known to have been permanently operated on a standard gauge road. Modern coupling devices make the operation of curves of less than 90 feet radius nearly, if not entirely, impracticable, and such radii are found only in yards, or city tracks. Street cars are operated over curves of 30 feet radii with some difficulty, but such curves are made with special guard rails, bent by machinery to true curves.

Vertical Alignment. — The alignment of a road considered in a vertical plane through the center of the track is called the grade

profile, or simply the profile. Grade profile is used to distinguish the profile of the finished road from the profile of the original ground surface along the center line before construction. The grade profile consists of straight lines called the grade lines, connected where they change in inclination by curves called vertical curves, which, as usually laid out, are arcs of parabolas, tangent to the grade lines.

Grade lines or gradients are designated by the vertical change in 100 feet. A grade rising 2 feet in a horizontal distance of 100 feet is called a plus, or ascending, 2 per cent, or two-nought, grade, commonly written + 2.0 grade; a grade line descending a half foot in one hundred is called a minus nought-five grade, written − 0.5, or − 0.5 per cent. Ascending and descending, on an original profile made for construction, refer to the direction in which the line is advanced in the survey. On the profile of an operating road these terms refer to the movement of traffic, and hence, an ascending grade in one direction being a descending grade in the other, the signs + or − on the drawn profile have no meaning, and should be omitted for single-track roads, but may reasonably appear on the separate profiles of double tracks.

Any grade from a 0.0 per cent, or level, grade to a 0.4 per cent grade may be called light; from 0.4 per cent to 1.0 per cent, moderate; from 1.0 per cent to 2.0 per cent, heavy; and over 2.0 per cent, very heavy. The character of the country through which the road is built will vary these limits somewhat. Eastern trunk lines seek grades 0.3 per cent or under against their heavier traffic, while grades of 4 per cent are frequent in the Rocky Mountains. A little over 4 per cent is the heaviest grade in regular use on any important road, but heavier grades, approximating 6 per cent, exist and are operated on some mountain, mine, and logging roads. A grade of 45 degrees would be a 100 per cent grade. A locomotive having only driving wheels and no tender could theoretically just maintain itself at a uniform slow velocity on a grade of about $24\frac{3}{4}$ per cent. The steepest trolley road grades are about 15 per cent.

The length of the vertical curve is important and should be

greater in sags of the grade line than at summits. In sags the length of the curve in feet should be one hundred times the change in inclination of joining grade lines divided by from 0.05 to 0.25; and on summits half as long. The reason for these easy vertical curves is to lessen the danger of breaking trains in two. There is little danger of this at a summit, but in passing a sag the forward end of a train begins to slow down as it reaches the grade of less or ascending inclination, the rear portion crowds ahead, producing slack couplings, and as the center of gravity of the train reaches the less steep or ascending grade, the slack comes out, with a greater or less jerk. This is practically obviated if the connecting curves change inclination no more rapidly than from 0.05 to 0.25 feet per hundred, which is secured by the rule given. If a descending 0.5 per cent grade is followed by an ascending 0.5 per cent grade, the change in inclination is 1.0 per cent, which, divided by 0.05 and multiplied by 100, gives 2000 feet as the proper length of connecting curve; if the divisor is 0.25, the curve is 400 feet long, which is commonly considered sufficient. The longer the curve, the better; but a long curve usually means increased earthwork cost, and the judgment is arbitrarily used in determining what shall be done. The greater part of existing vertical curves (1907) are much shorter than they should be, few being more than 400 feet long, regardless of the change in connecting gradients.

CHAPTER II

RAILS

Manufacture.* — Rails are designated by their weight per running yard. A 60-pound rail weighs 60 pounds per running yard, and has approximately 6 square inches in cross-section.

Rails in use in America are mostly made from Bessemer steel, though the tendency is to the open hearth process. Under the Bessemer process the molten metal is first cast in ingots about 16 inches by 18 inches by $4\frac{1}{2}$ feet. These are kept on end in a furnace known as the soaking pit until they are to be rolled. They are first rolled into bars between 7 and 8 inches square, known as blooms. The rough ends of the blooms are cut off and the blooms are reheated in a furnace and rolled into rails, or they may go immediately to the rolls without reheating, passing through a succession of rolls that gradually bring them to the desired form and dimensions. Each bloom makes a rail from 30 to 120 feet long, according to the section. The final rolls put the maker's name, date of rolling, and sometimes weight of the section, on the web of the rail. From the finishing rolls the rail goes to the saws and is cut in lengths of about 33 feet 6 inches. It is then cambered in a cambering machine just enough, determined by experience, so that it may cool straight. It is then taken to the hot beds to cool, and afterwards to the straightening press to be finally straightened by a process known as gagging, and for the smoothing of the rough ends left by the saws. The rail, which should have shrunk in cooling to 33 feet, is then measured, the holes for the joint bolts are drilled, and the rail is ready for the stock pile. Because of occasional imperfect ends a small percentage of the rails are made from 27 to 32 feet long, varying by whole feet.

* For full details of metallurgy and manufacture of rails, see any good work on metallurgy of iron and steel or any good encyclopedia.

There is a tendency toward the use of longer rails in order to make smoother track with fewer joints. For many years the standard was 30 feet. A standard of 33 feet was adopted by the American Railway Engineering and Maintenance of Way Association in 1904. Rails from 45 to 60 feet long are in regular or experimental use. It is very desirable that they should be as long as practicable. The principal difficulty with very long rails, besides the difficulty of handling, is the effect of change of temperature. The coefficient of expansion of steel is about 0.0000065, which means that 60-foot rails, touching at 130 degrees F., would be $\frac{7}{10}$ inch apart at the joints at -20 degrees F.

Chemical Composition. — The following chemical constituents occur in Bessemer steel rails: carbon, silicon, manganese, phosphorus, and sulphur. Carbon makes the rail hard; too much will make it brittle. American practice indicates that there should be from 0.35 to 0.55 per cent of carbon, according to the weight of the rail, the lower amount corresponding to the 50-pound rail and the higher to a 100-pound rail. French practice permits higher carbon. The tendency in America is to increase the carbon. Silicon makes the metal fluid and dense, producing solid ingots of fine grain. From 0.1 to 0.2 per cent is perhaps a proper allowance. Of manganese, which is required in the converter, chiefly to absorb the surplus oxygen from the air blast, there should be from 0.7 to 1.0 per cent. Phosphorus and sulphur are injurious impurities that cannot be wholly eliminated. The former produces brittleness, and the latter may cause the metal to be seamy. Not more than 0.07 per cent of either should be allowed, though as high as 0.10 per cent of phosphorus is sometimes permitted. Sulphur should be practically eliminated.

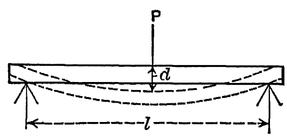
The Form of the Rail. — The form of the rail is very important. The form in most general use is that recommended by the American Society of Civil Engineers, which body has designed a series of sections varying by 5 pounds from 40 to 100 pounds.

The principles underlying the design are these: Rolling the metal at low temperature is very desirable, as it tends to make it hard and close grained. Therefore, the head should be small

and should not much exceed the flange in metal, in order that the rail may be rolled as cold as possible, and warp as little as possible in the cooling. The top of the rail should be broad and nearly flat (some noted engineers would make it flat), that the bearing of the wheel on the rail may be sufficient. The corners should be rounded for rolling, and the upper corners should be rolled to small radius, considerably less than the radius of the curve joining the tread and flange of the wheel, in order that the bearing on the corner shall be small. A contrary opinion has prevailed to some extent; namely, that the curve of the corner should fit the curve on the wheel. When this is so, the friction between wheel and rail is not only rolling friction, but sliding or grinding friction, and the rail wears rapidly, especially on curves. The action is partly sliding anyway, and the outer rails on curves eventually wear to fit the wheel, but this should be postponed as long as possible. For the same reason the sides of the head should be vertical instead of widening downward, although a slight widening will do no harm. There should be good bearing under the head for the fishing joints or splice bars. The flange should be wide enough to give good bearing and considerable resistance to overturning. With tie plates not so wide a base is necessary. The web need not be more than about ½ inch thick, but the rail should be high, to give stiffness. A stiff track requires much less power to operate than a flexible track. Mr. Dudley's experiments showed from 75 to 100 horsepower per mile saved by an 80-pound rail as compared with a 65-pound rail.

The stiffness* of a rail or any beam may be said to vary directly with the moment of inertia of its cross-section, which, in turn, in

* By stiffness is meant the reverse of flexibility: thus, the deflection (d) of a simple beam supported on points l units apart, and loaded with a concentrated weight of P units, equals $\frac{l^3 P}{48 EI}$, in which E is the modulus of elasticity of the material of the beam, and I the moment of inertia of the cross-section. Beams may be said to be stiff in inverse proportion to their deflection for a given load; and since this deflection is inversely proportional to the moment of inertia, the beam may be said to be stiff in proportion to its moment of inertia.



beams of similar cross-section, is proportional to the square of the area of that cross-section. Since the weight per unit of length is proportional to the area of cross-section, the stiffness is proportional to the square of the weight. Rails of one type but of varying weights are not of exactly similar section, but are so nearly so as to make the foregoing statement practically true. In rails of equivalent section the stiffness varies with the cube of the height and the first power of the breadth. Since the stiffer the track the less the work of maintenance and the less the power necessary to haul trains, there is economy in heavy, high rails. The economy cannot be shown with any precision, but is real, nevertheless. How far to go in the purchase of heavy rails is a matter of experience. The forces acting on rails are indeterminate. The weights acting through the wheels of the rolling stock may be known, but the effect of the blow-like load suddenly applied, and the distribution of the supporting forces exerted by the road-bed through the ties, are wholly unknown.

In accordance with the foregoing principles, the rail section shown in Fig. 1 was recommended. In this section, whatever the

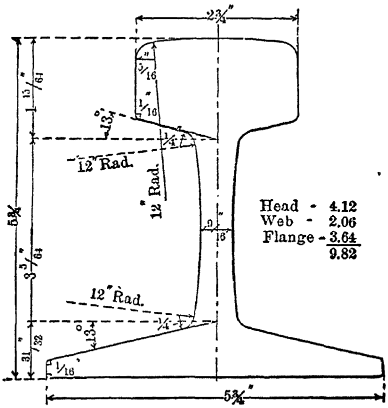


Fig. 1

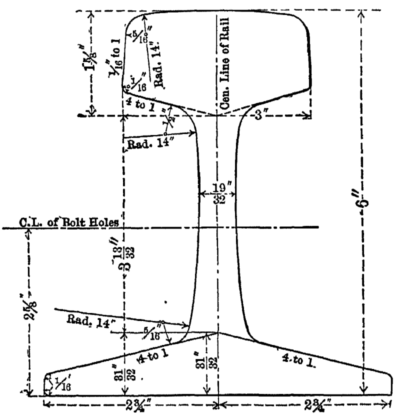


Fig. 2

weight, there is always 42 per cent of the metal in the head, 21 per cent in the web, and 37 per cent in the flange. The base width always equals the height; the radii of the top and corners are constant, as is the fishing angle.

The American Society of Civil Engineers section has been criticized by those using heavy rails as having a head too thick and so out of proportion to the flange as to prevent sufficient cold rolling. Whether this is true, or the softening of modern heavy rails is due to increased rapidity of finishing at a higher heat than necessary in order to produce more rails, dissatisfaction prevails, and a new section is being discussed (1907). The Dudley rail, designed for the New York Central & Hudson River Railroad, is an attempt to correct some of the supposed defects of the American Society of Civil Engineers section. It is shown in Fig. 2. A similar attempt has been made in the R. W. Hunt section, shown in Fig. 3.

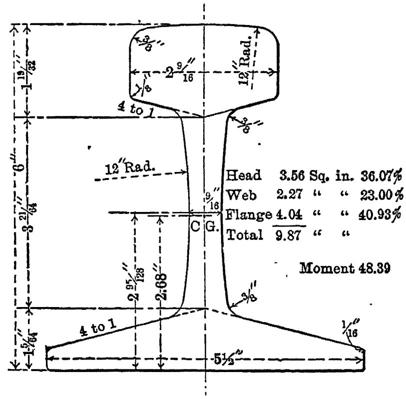


Fig. 3

For light traffic, rails should be from 70 to 80 pounds; for heavy traffic lines, 80 to 90 pounds may be laid; while for lines or parts of lines having particularly heavy and frequent trains, as large city terminals, 100-pound rails should be used.

The Life of Rails. — The life of rails cannot be given; it is estimated for 60- to 80-pound rails all the way from 100,000,000 tons of traffic to 200,000,000 tons; 100-pound rails may carry 500,000,000 tons. But this depends much on the distribution of the tons. Engines are supposed to cause rather more than half the wear. Rails lasting several years in the main track may be worn out completely in a few months when placed at the entrance to a very busy yard. The life is sometimes stated by trains as from 300,000 to 500,000 trains. Captain R. W. Hunt, an authority on rails and steel, says that trunk line rails ought to last about ten years. About half the head is available for wear, but only about ¼ inch should be allowed to be worn off in the main track.

After this wear the rail should be placed in siding or yard service. It is a recent practice to reheat and reroll partially worn rails, to give them a perfect section of slightly less than the original weight. In very many cases rails are removed for bent or battered ends before the full permissible abrasion has occurred.

Rail Specifications and Inspection. — Rail specifications should include inferior and superior limits for carbon, silicon, and manganese, and superior limits for phosphorus and sulphur. They should state weight, form of section, percentage of short rails to be allowed, spacing and size of joint bar holes, and the kind of tests to be met by acceptable material. In general, specifications should state results to be secured rather than methods of manufacture.*

Rails should always be inspected at the mill for the purchaser by a competent, experienced, and reliable inspector.

* For complete specifications see "Manual of Recommended Practice," American Railway Engineering and Maintenance of Way Association.

CHAPTER III

RAIL FASTENINGS

JOINTS

Requirements. — Not all the requirements of a perfect rail joint are met by any form yet devised. It is doubtful if any perfect joint can be devised for the present form of rail and support. The joint should be such as to make the jointed rail act as a continuous rail; that is, the joint should have exactly the same strength and stiffness as the middle of the rail. The rail moves with a wavelike motion in front of the advancing wheel. This is partly due to the settlement of the ties, and partly to the bending of the rail, which also bends under the wheels between or over settling ties. The portion of rail at or near a joint should bend as other portions of the rail. The ends of the rails must be held in true surface under a passing wheel, that one may not be battered. The rail should be so rigidly supported that it will not bend at all.

Types. — There are two distinct types of joints used on American railroads. 1. The angle bar. 2. The bridge joint, which may or may not be combined with an angle bar.

The ordinary angle bar is shown in Fig. 4.

Two modifications, known as the 100 per cent and the Bonzano joints, respectively, are shown in Figs. 5 and 6.

The two commonest forms of bridge joint are the "Weber" and the "Continuous," shown in Figs. 7 and 8.

Joints are either supported (that is, the rail ends fall on a tie known as the joint tie) or suspended (that is, the rail ends fall between two ties called shoulder ties). The bridge joint is a suspended joint, the rail ends being supported on a metal base extending between shoulder ties.

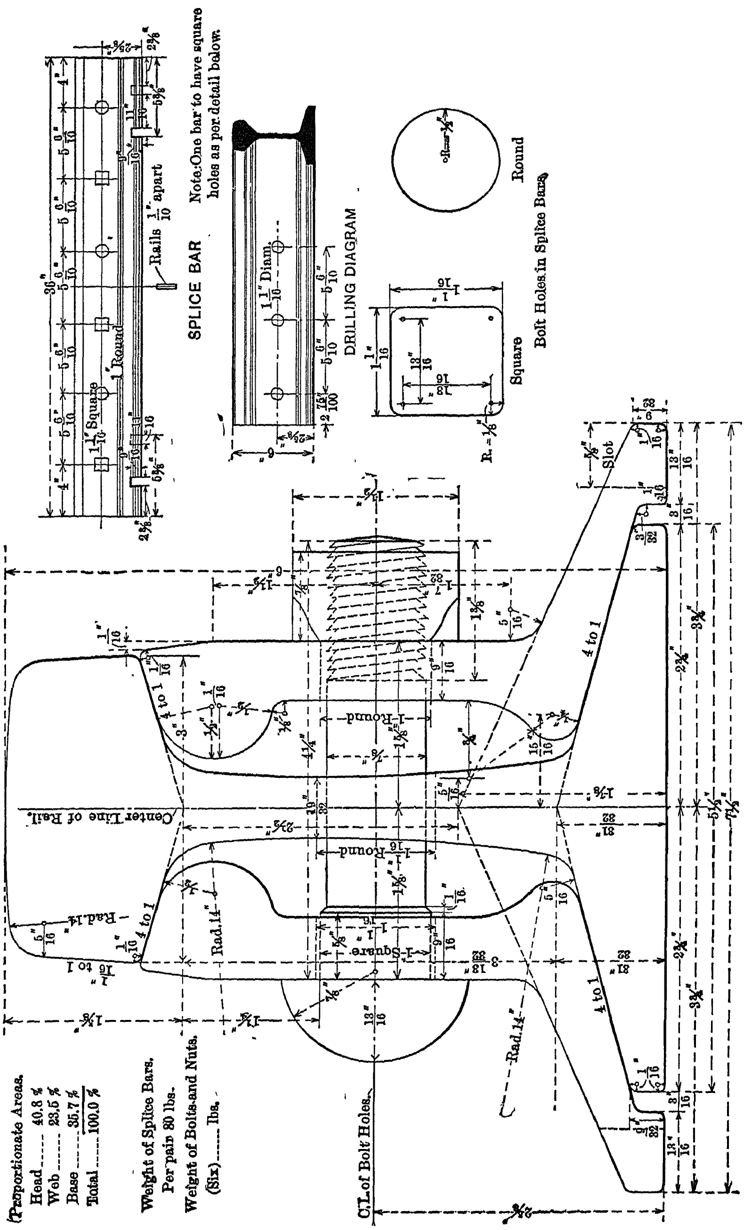


Fig. 4. N.Y.C. and H.R. R.R. Standard 6 Bolt Angle Bar Joint.

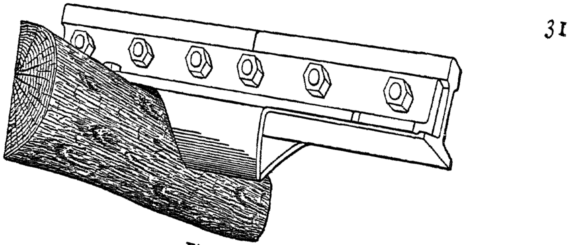


Fig. 5

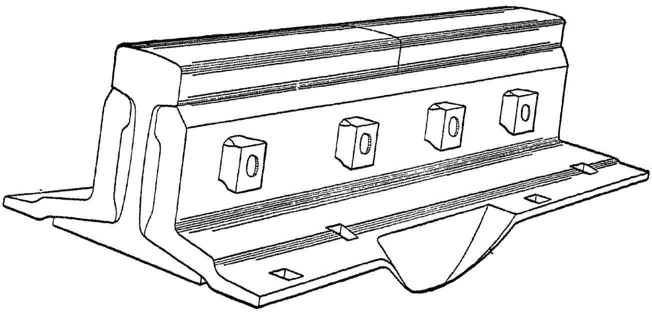


Fig. 6

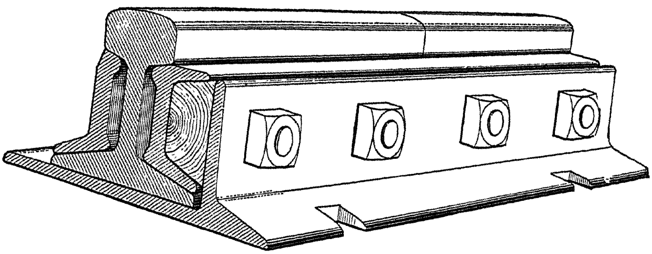


Fig. 7

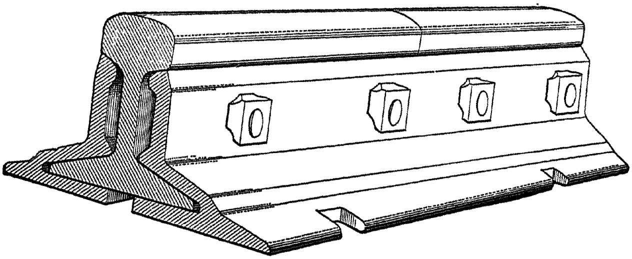


Fig. 8

Joints are made opposite or staggered; that is, the joints in one line of rails are opposite the joints in the other line or opposite the centers of the rails of the other line. Staggered or alternate joints are the more used. Which of the two gives the safer track has never been determined, but alternate joints would seem to be the better for well-maintained track; while for track not well ballasted, or likely to be poorly kept up, opposite joints are perhaps safer, giving harder blows on the joint or shoulder ties, but less roll to the locomotives and cars.

Joint Action. — If the joint yields, — and it usually does, — the advancing wheel jumps the depression and delivers a blow on the forward rail a little beyond the end. Observation of almost any track will show the effect of this blow on the rail. On single track all rails will be hammered at both ends. On double track each rail will be hammered on one end.

If the rail yields under the load of the passing wheel, — and it usually does, — a portion of the load of the passing wheel comes on the joint bar. If the rail has no support under its base, the fishing angle under the head causes a lateral thrust, tending to force the bar out from the rail. This thrust is carried by the bolt heads and nuts to the bolts. The continual recurrence of this thrust gradually loosens the nuts, thus loosening the bars and taking away the support under the head of the rail. Therefore, some form of joint supporting the rail base rather than the rail head is desirable. This suggests that some form of bridge joint will be the future generally used joint if the present T rail and cross-tie construction is retained.

Angle Bars. — Angle bars are rolled in long bars and sawed to required lengths. They vary from 20 inches long with four bolts, to 48 inches with six bolts. For a supported joint the angle bar should be about 24 inches long with four bolts. For a suspended joint the bars may be from 24 to 30 inches long with four bolts, while for three-tie joints — supported joints — the bars should be from 36 to 40 inches long with six bolts. Some roads use an angle bar extending over the base of the rail to a bearing on the tie. Angle bars will weigh from 45 pounds per pair for 20-inch

bars to about 70 pounds or more per pair for 40-inch bars. They should be proportioned to the weight of the rail, and should be heavier for a three-tie joint than for a suspended joint, because when the joint tie of a three-tie joint yields, the unsupported span is greater than that of a suspended joint.

Bolt holes in angle bars are punched approximately oval in form to fit the oval portion of the bolts. This keeps the bolts from turning when the nuts are being screwed home.

Angle bars are usually made of softer steel than the rails, but the correctness of this practice may be doubted, although it is endorsed by the American Society for Testing Materials. Specifications should give the form of the bar, both spacing and size, limits in chemical composition, ultimate strength and elasticity, manner of testing, and definite statements of what will cause rejection of material or finished bars.*

Bolts. — The bolts used with angle bars are made oval under the head. They are usually from $\frac{3}{4}$ to $\frac{7}{8}$ inch in diameter, and from $3\frac{1}{2}$ to 5 inches long, under the head. The bolt should project but little beyond the nut when the latter is set up. The nuts may be square or hexagonal. Square nuts are generally used. Nuts are held in place by some form of nut lock. The Harvey grip-thread bolt and nut have ratchet threads so cut as to jam when set hard against the joint bar and hold by friction. A bolt

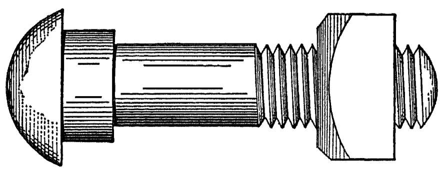


Fig. 9

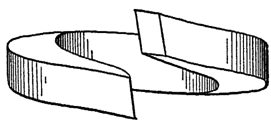


Fig. 10

and nut lock are shown in Figs. 9 and 10. Bolts are shipped in kegs containing about 200 pounds.

* For specifications see "Manual of Recommended Practice," American Railway Engineering and Maintenance of Way Association.

SPIKES

Hook-Headed Spike. — Rails are held to cross-ties by spikes. The ordinary form of hook-headed spike is shown in Fig. 11. It is a poor fastening. Lag screw spikes and various forms of bolts have been used, but general American opinion is that as yet nothing better than the spike has been devised, economy, convenience, and safety all considered. An improved form of spike is the Goldie, ground to a sharp point. In driving, it tears the wood less than the ordinary form. A better form of fastening is desirable. It is doubtful if the American preference for the spike is justified. Spikes are $\frac{1}{2}$ or $\frac{9}{16}$ inch square by 5 or $5\frac{1}{2}$ inches long, measured under the head, as shown in Fig. 11. Extra long spikes of 7 inches are made for use where a long spike is necessary, as in the headblocks of switches. Four spikes are driven into each tie. Spikes are shipped in kegs containing 200 pounds.

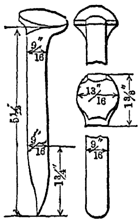


Fig. 11

Screw Spikes. — Screw spikes (Fig. 12) are very largely used on the European continent and are now being experimented with in America (1907). Their cost is somewhat more than the cost of spikes, and the cost of driving them even by machines exceeds the cost of driving spikes. Holes must first be bored in the tie. They are of a diameter equal to that of the screw shaft at the base of the thread. Screw spikes hold better and longer than ordinary track spikes, requiring less frequent respiking. Their holding power is from two to five times that of the ordinary spike, the greatest advantage being in soft woods, and the least in oak, or other hard woods. They do not tear the wood fiber of the ties, nor cause cavities for holding water. There seems to be good reason for adopting them, particularly for use with chemically treated soft-wood ties, which wear out before they

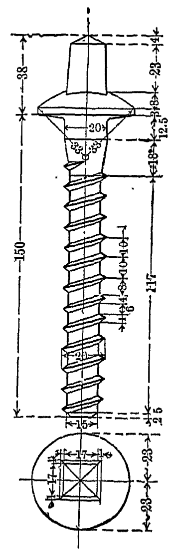


Fig. 12

decay, in order to get the full value of the preservative treatment.*

These screw spikes as used in France and Belgium weigh about 18 ounces each. It is estimated that they will cost from 4 to 4½ cents in the United States.

BRACES

Rail braces (Fig. 13) of cast or pressed steel or malleable iron are used on curves and at switches where there is or may be excessive lateral pressure on the rails. Practice varies as to the number used. It is suggested that there be four braces to each rail on curves of from 3 to 6 degrees, six braces to each rail on curves from 6 to 10 degrees, and a brace on every alternate tie for sharper curves than 10 degrees. Braces would seem to be needed on the outer rail only, but they are frequently put on the inner rail as well, and when so placed, are placed on the same ties that carry the outer braces. These inner rail braces brace the rail against the thrust of heavy slow trains, and relieve the spike heads from any possible pull on the tie caused by the thrust on the outer rail.

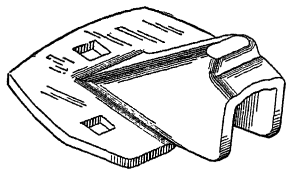


Fig. 13

TIE PLATES

Metal tie plates placed between the rail and tie lengthen the life of a tie that cuts, and, if properly designed, increase the efficiency of the spike fastening in holding the rails to gauge and to the ties.

The wave motion of the rail under the rolling loads causes a wide tie to tend to rock in the ballast, and thus work loose. It also loosens the spikes. Therefore the best bearing would be a

* For full discussion of various forms of screw spikes, machines for driving them, and their use in Europe, see paper by Mr. Hermann Van Schrenk, Bulletin No. 50, Bureau of Forestry, U. S. Department of Agriculture.

narrow top and wide base. For this reason tie plates should be made narrow on top, but wide enough on the bottom to cover the whole width of a tie. Tie plates are made from $3\frac{1}{2}$ to 6 inches wide. They should be stiff enough to prevent bending under the loads. They may be held firmly to the tie by lugs or ribs on the bottom to be driven into the tie. Two forms are used, chisel-pointed lugs driven into the tie across the grain, and wedge-shaped ribs driven with the grain. With a given thickness of plate the ribbed plates are stiffer, but the chisel-pointed lugs give the greatest holding power against lateral displacement. It is possible that flat-bottomed thick plates are to be preferred. The efficacy of the lugs or ribs is doubtful. In Europe they are little used. The Southern Pacific and Pennsylvania railroads find flat-bottomed plates preferable.

The plates may have lugs or ribs on top to assist in holding the rail in place. These are sometimes lengthwise with the rail and sometimes transverse. They should exist in one form or the other. The flange needs bracing on the outside and holding

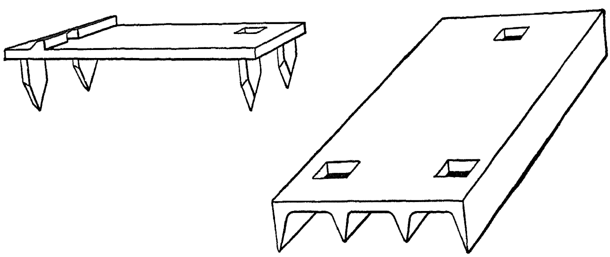


Fig. 14

down on the inside. Two forms of tie plates are shown in Fig. 14.

European tie plates are heavier than those used in America. There the rails are tipped toward the center, that the coned wheel tread may bear fairly on the top of the rail. The tie plate is fashioned accordingly. This is probably good practice, and might well be adopted in the United States.

The use of tie plates is recent, but is rapidly increasing. The practice varies, from their use at joints only, joints and half rail

points or more on curves, to a plate for every tie. Soft-wood ties should have plates on every tie. Hard-wood ties that fail from decay need plates only where the wear is excessive, or there is great lateral pressure. Such places are joints, curves, and track near large stations, or in yards, where the intensity of traffic is considerable. Preserved ties should be protected with plates.

Spike holes are made in the plates, sometimes two, sometimes three. When three holes are made they are arranged for two spikes on the outside and one on the inside of the rail. This, though approved by some eminent railroad men and organizations, is believed to be the less defensible practice. To hold the rail against overturning outward, two spikes on the inside are better than one, and when tie plates are used all three spikes are brought into play in resisting lateral displacement, no matter on which side of the rail they are driven.

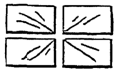
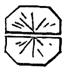
CHAPTER IV

CROSS-TIES

Material. — Cross-ties, usually called simply ties, are made of various kinds of wood, and sometimes of steel. Concrete ties and ties of reinforced concrete are in experimental use.

Wood for ties should be hard, should hold a spike well, should not rot rapidly, and should be fairly straight grained. While the wood should have these characteristics, the best wood furnished by the country through which the road is built is what is frequently used. Where no forests exist and ties must be brought in, the best wood obtainable for the money available is used. Long leaf Southern pine is being largely used on roads in the northeastern United States. White oak is considered one of the best, if not the best of woods for ties. Chestnut is considerably used in the territory where it grows, and makes a good tie, but requires careful inspection, as it is apt to be unsound. Cedar, white pine, tamarack, and other soft woods are used to some extent. In the southwest Bois d'Arc is somewhat used. On the Pacific coast redwood and Oregon pine (Douglas fir) are used; the latter is hard and durable, the former soft, does not soon decay, but cuts under the rail and the spiking soon destroys it. Redwood ties with an oak bearing piece have been tried. Redwood with tie plates makes an excellent tie, and will last under favorable conditions from twelve to fifteen years.

Form and Size. — Wooden ties are from 7 to 9 feet long for ordinary track, the shorter length being used only in street railway or light steam road track. Ties longer than 9 feet are used for special work, as on bridges and at switches. The usual lengths are 8 feet and 8 feet 6 inches. The cross-section varies with the character of the track and the part of the tree or size of the tree from which the tie is cut. Ties as small as 5 by 6 inches are

used in light street track, while ties 7 by 10 inches are used in some heavy track. The commonest size is 6 by 8 inches, the smaller dimension being the depth. Ties are known as pole, quarter, and slab, according to the cut from the tree. A pole tie is cut from a trunk just large enough to furnish one tie; the cross-section is of this form:  According to standard specifications such a tie should have parallel faces not less than 6 inches wide. A quarter tie comes from a trunk making four ties, thus:  Such a tie should be of full required dimensions. A slab tie is from a log giving two ties, thus:  These ties should be full size.

As tie timber is becoming scarce, a form adopted largely in Europe is recommended for ties to be treated by chemical preservative processes. This tie has a narrow top and wide base, as shown in the figure , contains some sap wood, and is of a form permitting two ties to be obtained from a stick that would give but one rectangular tie. The narrow top and wide base are theoretically and practically desirable, the wide base distributing the load over a large area of ballast, and the narrow top diminishing the tendency to rock under the wave action of the rail. Tie plates should be used on all such ties unless the rail has a very wide base. Under the heavy loads now run over American rails a broad tie 7 inches thick is desirable. For economy in tie production a uniform classification of ties based on dimensions is desirable. Ties may then be gotten out by lumbermen with reasonable certainty that if of sound material they will meet the specification of some road and may be sold. Such a classification adopted by the American Railway Engineering and Maintenance of Way Association, March, 1904, is: —

Class	Breadth, Inches	Thickness, Inches	Length, Feet
A	9	7	8, 8.5 or 9
B	8	7	8, 8.5 or 9
C	9	6	8, 8.5 or 9
D	8	6	8, 8.5 or 9
E	7	6	8, 8.5 or 9
F	6	6	8, 8.5 or 9

Tie Making. — Timber for ties is best cut in the period when the sap is not flowing, as in the winter in northern latitudes. Ties should be thoroughly seasoned before being used, as their life in the track is thus materially increased. The seasoning should not be less than six months, and need not exceed twelve months. Ties are either hewn or sawn. A hewn tie as a rule has irregular ends due to cutting to length with an ax. The ends of all ties should be sawn square, bringing the ties to the specified length. Hewing requires a better stick for working than sawing. Sawing

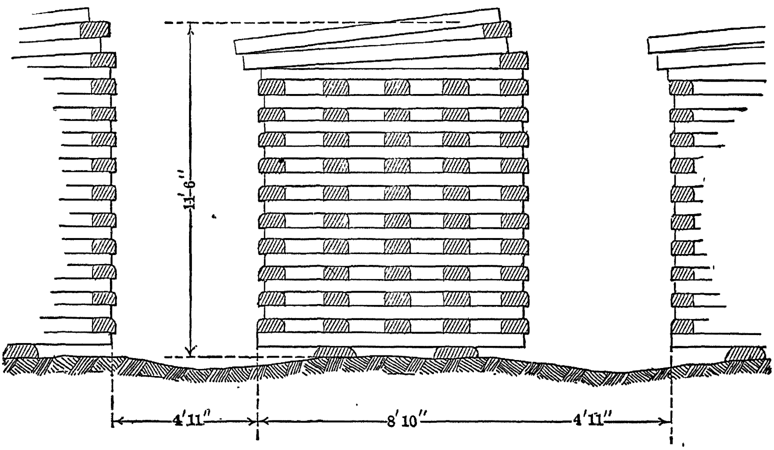


Fig. 15

must of necessity be somewhat across the grain, and if carelessly done may give a badly cross-grained tie. Sawing also leaves a rough surface holding moisture. For these reasons hewn ties have been generally preferred. At least one engineer claims he has secured better results with sawn than with hewn ties. The question is a disputed one. If the ties are treated with a preservative they are usually sawn, and excepting for the danger of cross-grained ties being overlooked by the inspector, the objections to sawing do not hold for treated ties. Sawing may result in economy of timber. Ties should be flat under the rails and are sometimes "spotted"; that is, made smooth and flat where

the rail is to bear. Special machines for doing this work have been devised. A sawn tie needs no such treatment. No sap wood should appear in the body of a tie. It cannot always be avoided on the corners, nor on the sides of a pole tie. After cutting, ties should be carefully piled for seasoning. The form of the pile is important. No tie should touch the ground; they may be piled on blocks or on string pieces. The ties should be well apart to permit circulation of air; the top layers of a pile should form a roof to shed water. A good form of pile is shown in Fig. 15.* The ties should be piled for seasoning in the woods, that they may not season too rapidly. Rapid seasoning causes checking or splitting. The inspector examining the piled ties puts a round spot of paint on the ends of those he accepts, and a cross on those he rejects, which are known as "culls."

Durability. — Wooden ties fail in one of three ways: 1. They decay. 2. They "cut" under the rail. 3. They become spike worn (called "spike sick" or "spike killed"). Some woods that do not decay rapidly are finally ruined by redriving of spikes. Some soft woods decay rapidly around the spike, requiring frequent redriving, which soon wears them out.

In the case of hard woods, cutting under the rail is not a real mashing of the new wood of a tie; it is due to the vibration of the rail, which wears away a partly weathered or softened surface, exposing new surface to the action of the weather. With soft woods the fiber may be actually crushed. Cutting is almost entirely prevented by the use of a proper form of tie plate. Ties fail most frequently by decay. The life of a tie depends on the kind of wood, the time of cutting, degree of seasoning, and the climate and soil in which it is used. The average life is usually placed at eight years. The following table† is given, showing the average life of various kinds of untreated woods.

* From Bulletin No. 14, Bureau of Plant Industry, U. S. Department of Agriculture, showing French practice.

† Mr. Filiburt Roth in Bulletin No. 10, Forestry Division, U. S. Department of Agriculture.

White oak and chestnut oak	8 years
Chestnut	8 years
Black locust	10 years
Cherry, black walnut, locust	7 years
Elm	6–7 years
Red and black oaks	4–5 years
Ash, beech, and maple	4 years
Redwood	12 years
Cypress and red cedar	10 years
Tamarack (larch)	7–8 years
Long leaf pine	6 years
Hemlock	4–6 years
Spruce	5 years

Catalpa lasts well, fifteen years being given as its average life. It has but recently received much attention, but has been found to thrive and grow rapidly in the Eastern States. European white oak is a more durable wood than the average American white oak. This fact must be remembered in comparing published reports of European and American practice.

Ties used in the southern United States have a shorter life than those used in the Northern States. This is largely due to differences in moisture and temperature. Ties laid in some portions of the western table-lands last many years. This is due to the antiseptic character of the alkali soil, and the dryness of the climate. Green ties are shorter lived than seasoned ties. According to the character of the wood, well-seasoned ties will last from one to three or more years longer than ties placed in the track green.

The matter of the life of ties is of great importance. About one seventh of the entire cost of maintenance of way in the United States is for tie renewals. This is twice the cost of rail renewals. With the cutting off of the good timber of the country the cost of ties is increasing rapidly. A tie that could be had a few years since for from 35 to 50 cents will now (1907) cost from 50 to 80 cents, and the price is likely to increase.

Any practice or method that will lessen the item of tie renewals will receive close attention of operating managers. Five general ways of reducing this item may be suggested: 1. Treating the tie

with some form of preservative to prevent early decay, thus somewhat lengthening the life of expensive hard-wood ties, and also, what is of more importance, greatly increasing the life of cheap soft-wood ties. 2. The use of mechanical devices for protecting ties from wear, as tie plates, spike dowels, screw spikes, etc. 3. Made possible by the first and second methods, more economical methods of cutting ties from the log, getting two ties from a log that with present methods yields but one. 4. Using metallic, concrete, reinforced concrete, or other ties not subject to decay or rapid wear. 5. Building an entirely different form of track support, using longitudinal concrete or reinforced concrete supporting pieces. The fourth and fifth methods are as yet too costly to introduce generally, but the fourth bids fair to be soon adopted and the fifth will ultimately prevail.

Timber exposed to alternate wet and dry conditions in the presence of earth decays rapidly on the outside. This is the condition of railroad ties bedded in poor ballast in the eastern United States. In the western highlands, where the soil is alkaline, and the moisture little, and in the Eastern States, where high-grade, quickly draining ballast is used, the external decay is not so rapid. Worn spike holes serve to hold water and hasten decay more than rail bearing. Timber exposed to the atmosphere, but raised from the ground, as bridge timbers, decays first on the inside, said to be due to fermentation of the sap. Covered timber, as the unexposed timber of covered bridges, or timber in the dry air of houses, practically never decays. Moisture is thus necessary to the decay of timber. Ties cannot be kept entirely free from moisture. They may be somewhat protected from the effect of fermentation by the introduction of antiseptic substances. One or both of these results is the object of treatment with preservatives. The softer, more open grained, and less durable woods are the more easily treated, and give relatively better results than treated hard woods.

Preservative Processes. — There are a number of processes for treatment, known by the names of the inventors of the devices by which the ties are treated, or the chemical used. The commonest

processes are Kyanizing, Burnettizing, zinc-tannin, and Creosoting. Kyanizing consists in treating the timber to a bath of corrosive sublimate (chlorid of mercury). This process is somewhat dangerous because of the poisonous character of the chemical, and is not much used. When used, however, it yields excellent results. Burnettizing consists of forcing chlorid of zinc into the wood cells. This process and the modification of it, known as the zinc-tannin, or Wellhouse, process, are extensively used. The zinc-tannin process first treats the ties to the chlorid of zinc solution, then to a solution of glue, or gelatine, and follows this with a solution of tannin. The glue and tannin form an insoluble leathery substance closing the pores of the timber, preventing the washing out of the zinc salt which is soluble. The glue is sometimes introduced with the chlorid solution, saving one operation. Creosoting consists in forcing dead oil of coal tar (commonly called creosote) into the pores of the wood. Creosoting is the most effective, but the most expensive of the processes named. Zinc-creosote is the name given a process in which the zinc solution of the Burnette method is followed by an injection of dead oil of tar.

Burnettizing. — The details of this process vary according to the character of the wood treated and the thoroughness of treatment. For green ties the process is essentially as follows: The ties are loaded on small cars, which are run into an iron cylinder whose ends are then hermetically closed; a partial vacuum is then created in the cylinder, after which the cylinder is filled with live steam under low pressure. After fifteen or twenty minutes the steam is pumped out and a second vacuum created and maintained for a few minutes, after which the cylinder is again filled with live steam under low pressure, and this condition is maintained for several hours, three to six, according to the kind and condition of the timber. The steam is then blown off and a third vacuum created, after which the cylinder is filled with a solution of chlorid of zinc under a pressure of about 100 pounds per square inch, which is maintained for one or two hours. The solution is then withdrawn, the cylinder opened, the cars run out and un-

loaded, and a new load run into the cylinder. The entire treatment requires from ten to thirteen hours. At some plants the first vacuum and first steaming are omitted and the one steaming given is of shorter duration. At such plants the process requires from eight to ten hours. The steaming is to soften the cells and their contents, and the vacuum to extract the sap and water from the wood. The cylinders used are a little over 100 feet long, about 6 feet in diameter, and take from 350 to 400 ties at a charge.

The degree of vacuum varies from 14 to 26 inches, the steam pressure from 18 to 30 pounds, the strength of the chlorid solution from 2 degrees Beaume hydrometer (about 1.5 per cent of chemical) to 2½ degrees Beaume (about 1.7 per cent chemical). A green tie will absorb from 4 to 5 gallons of solution and, depending on the strength of the solution, from 0.75 to 0.9 pound of chlorid. The ties should be stacked and dried for from four to six weeks after treatment. In Europe only seasoned ties are used, and the entire steaming process is omitted, constituting a material saving in cost. Thoroughly air-dried ties probably need no steaming. The cost of treating ties by this method varies with the price of chemicals, fuel, and labor. For the more elaborate process here described, a cost of from 9½ to 12 cents per tie 6 inches by 8 inches by 8 feet is stated by Mr. Kruttschnitt of the Southern Pacific Company.

Wellhouse or Zinc-Tannin Process. — As usually practiced this process is the same as the Burnettizing up to the introduction of the zinc chlorid solution. To this solution, before running into the cylinder, a small percentage of dissolved glue is added. About 2 pounds of glue to 100 gallons of solution are used. After this solution has been forced into the timber, the cylinder is emptied, a solution of tannin (extract of hemlock bark) is run in, the pressure raised to 100 pounds per square inch, and maintained for about one hour, after which the solution is run out, the cylinder opened, and the charge of ties withdrawn. The tannin and glue form an insoluble leathery substance, closing the pores of the timber, thus preventing the washing out of the soluble chlorid. The ties should be stacked and dried for from four to six weeks.

The tannin solution contains about 0.5 per cent of tannin. With but two vacuums and one steaming, this process requires about nine hours. The cost has varied from 10 to 15 cents per tie for green ties.

Creosoting. — In this process dead oil of coal tar is generally used, though wood creosote oil has been used to some extent. The creosote oil is said to be less dense, sooner washed out, and therefore less efficient than dead oil of tar. The oil is heated to about 170 degrees F. for use. The process is essentially similar to Burnettizing, except that the dead oil is used in place of the zinc solution. The steaming may be double with three vacuums, or single with two, or omitted altogether, and but one vacuum created, followed at once by the introduction of the oil. The pressure used in forcing the oil into the wood is from 80 to 100 pounds per square inch. This pressure is maintained for from one to two hours or longer; longer if the wood is not steamed. With the double steaming the entire process requires eighteen to twenty hours. From 10 to 12 pounds of oil per cubic foot of wood are required; 10 pounds per cubic foot gives about 27 pounds per tie. The oil weighs about 8.7 pounds per gallon. About 3 gallons per tie — a little more — are required. With open, porous woods more oil is required. In France and Germany as much as 30 pounds per cubic foot is sometimes used. The price of oil varies, but may be averaged at, say, 1 cent per pound. Ten pounds per cubic foot of timber would then cost 27 cents per tie 6 inches by 8 inches by 8 feet for oil only. For labor, fuel, depreciation, and profit, from 17 to 21 cents must be added, giving close to 50 cents per tie for treatment by creosoting. Creosoting being acknowledged to be the most efficient method of treatment, efforts have been made to reduce the cost. A method called Rüping, from the name of the inventor, puts the timber first under pressure instead of partial vacuum, then forces the oil into the cylinder without reducing the pressure. After a suitable interval the pressure is relieved, the oil run out of the cylinder, and a vacuum established. The air first compressed in the wood cells now expands and forces all surplus oil out of the wood. The

saving of oil is estimated at from 50 to 60 per cent. This would bring the cost of the method down almost to that of the zinc-tannin process. Only thoroughly air-dried timber is used.

Comparisons. — 1. *Durability of treated ties.* The chlorid of zinc is soluble and in moist soil or climate soon washes out of the tie. In the dry Western States Burnettized sap wood pine ties will last from twelve to fifteen years as an average. In more moist regions the life will be much less. The Wellhouse or zinc-tannin process increases the life in moist climates, — how much is not known, — but is probably not worth the extra cost for ties used in the drier Western soils. The life of creosoted ties is unknown. Well treated, they will be destroyed by use rather than decay. Creosoted wood used for piling and bridge timbers has an unknown life, all that has been well treated in the United States being still in use, except where removed for other causes than decay. It is supposed to be nearly indestructible.

2. *Economy.* The use of comparatively poor timber for railroad ties assures a lengthened life for the hard-wood forests, and is thus of a value not directly measurable in money. To determine whether treatment is directly economical, four items must be considered: 1. First cost of the ties. 2. Life of the ties. 3. Cost of replacing ties. 4. Interest rate for money. If immediate expenditure is the governing matter, — immediate meaning expenditure within two or three years, the life of the cheapest, poorest ties, — only relative first cost need be considered. But this is rarely good policy. Three other methods of comparison are suggested, the first of which is the one commonly given, the second not usually stated but believed to be the safest of the three to follow, and the third apparently most closely in accord with the actual conditions.

(1) The relative merits of two or more ties are compared on a basis of annual cost, that tie being the cheapest which shows the least annual cost. The annual cost is made up of: 1. Interest on first cost in the track. 2. Annual sinking fund to provide for the cost of renewal at the expiration of the life of the ties. While it would perhaps be economy to establish a sinking fund

for renewals of perishable portions of a railroad property, no such sinking fund is usually established. What eventually comes about is a renewal each year of about that portion of the whole of the ties that is represented by the reciprocal of the life of the ties. If ties last on an average of seven years, about one seventh are renewed annually. While this is not strictly true, it is so nearly true that it is considered safe to determine the relative merits of two or more ties by the following method: —

(2) The relative merits of two or more ties are compared on a basis of annual cost, which is assumed to be made up of: 1. Interest on first cost in the track. 2. First cost in the track divided by the life of the tie. The result is probably always more favorable to the cheaper tie than that of the first method, though the difference is not great. The second method is recommended on the theory that where comparisons made on uncertain data depending on future contingencies are close, it is usually safe to adopt the article or procedure involving the least present expenditure.

(3) The relative merits of two or more ties are compared on a basis of total cost for a definite business period, the total cost being assumed to be the ultimate amount of the first cost at compound interest, and each renewal at the same rate, at the expiration of the given period. The period should be short; probably not much in excess of the life of the most durable tie in the comparison, and certainly not more than a period equal to the least common multiple of the several lives. The difference in total cost discounted to the present time shows the present advantage of the tie of least total cost. If a tie that will last seven years costs 40 cents, and money is worth 4 per cent, and it is desired to know how much may be paid for a tie that will last three years, the first and third methods of comparison will give identical results, the second a result somewhat larger than the other two, and therefore, it is believed, on the side of safety.*

* The sum S to which a given principal P will amount if placed for n years at compound interest of rate r is

$$S = P(1+r)^n. \qquad (1)$$

If the compounding is t times a year, the formula becomes

$$S = P\left(1+\frac{r}{t}\right)^{nt}. \qquad (2)$$

The sinking fund F that must be deposited annually at the end of the year at compound interest of rate r to discharge a given sum S in n years, is

$$F = \frac{Sr}{(1+r)^n - 1}. \qquad (3)$$

The present value P of a sum S to be realized n years hereafter is that amount which placed at compound interest will amount to the given sum at the expiration of the stated period, and hence, from (1)

$$P = \frac{S}{(1+r)^n}. \qquad (4)$$

If a given principal P is placed at compound interest for a period of k years, and at the beginning of each succeeding period of k years an equal amount of principal is added to the whole for n such periods, the total sum at the expiration of the n periods of k years will be

$$S = \frac{P(1+r)^k[(1+r)^{nk} - 1]}{(1+r)^k - 1}, \qquad (5)$$

and the present value of this sum is

$$V = \frac{P(1+r)^k[(1+r)^{nk} - 1]}{(1+r)^{nk}[(1+r)^k - 1]}. \qquad (6)$$

If two ties, or any other two things, lasting n and n' years, are to be compared by the first or third methods mentioned above in the text, and the cost of one is desired in terms of the cost of the other, the two costs to be such that for the given lives the two ties may show the same value, this cost is found from the following formula, in which c is the cost of the tie lasting n years and c' the cost of the tie lasting n' years,

$$c' = c\left[\frac{(1+r)^n}{(1+r)^{n'}} \cdot \frac{(1+r)^{n'} - 1}{(1+r)^n - 1}\right].$$

To compare these costs by the second method given

$$c' = c\frac{n'}{n}\left(\frac{nr+1}{n'r+1}\right).$$

By these two formulas the sums that may be paid for a tie lasting three years, if one lasting seven years costs 40 cents and money is worth 4 per cent, are respectively 18.53 and 19.56 cents.

The equations for c' are based on equal annual cost.

If a treated tie costs 80 cents in the track, and lasts sixteen years, while an untreated tie costs 50 cents and lasts eight years, money being worth 4 per cent, the relative values by the three methods are as follows: —

1. First cost	$0.800	$0.500
Interest	0.032	0.020
Sinking fund	0.0367	0.0543
	$0.0687	$0.0743

Difference in favor of treated tie, $0.0056 + per year.
Capitalized excess value of treated tie, $0.14.

2. Interest	$0.032	$0.020
First cost ÷ life	0.050	0.0625
	$0.082	$0.0825

Difference in favor of treated tie, $0.0005 per year.
Capitalized excess value of treated tie, $0.0125 — a practical balance.

3. First cost at compound interest for sixteen years	$1.498	$0.936
One renewal for eight years		0.685
	$1.498	$1.621

Difference in favor of treated tie, $0.123.
The present value of which is $0.066 —.

If the treated tie is to cost 80 cents, the untreated tie to show the same value must be had in the track for $46\frac{2}{10}$ + cents by the first and third methods, and for $49\frac{7}{10}$ cents by the second method.

Precision in such estimates is impossible, for though the mathematical formulas may be entirely correct with their several bases of assumptions, the data are of necessity but estimates. There is always an indeterminate element of cost in the annoyance, delays, etc., involved in track changes. Because of the destruction of forests, ties are constantly increasing in cost. It is probable, therefore, that if the money is available to purchase the longer-lived tie, when the comparison by any method shows nearly equal values, it is the tie to buy; whereas if the present income is small,

with a prospect of future increase, the cheaper tie should be purchased.

Spike Dowels. — There is warrant for any device of reasonable cost that will increase the wearing life of a tie that has been chemically treated to preserve it from decay. Tie plates partially serve this purpose; screw spikes are useful. The most recent device is the spike dowel largely used in Europe. This is a screw plug of fine-grained, creosoted wood (beech or birch) screwed into the tie to receive and hold the spike. The plug is

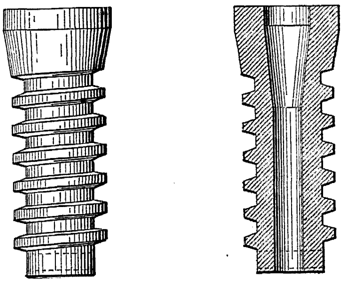


Fig. 16

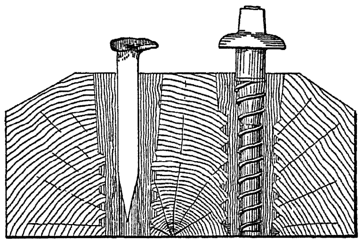


Fig. 17

much larger than the spike. A hole for the spike is bored through the center of the dowel. The holding power of the spike in the dowel is greater than in the tie, the wear of the tie about the spike is prevented, and the dowel may be replaced when worn out. The cost of six such dowels in a tie (the European practice is to use six spikes instead of four to a tie) is estimated at 26 cents. At this price it is doubtful economy to put them in new ties, but almost certain economy to put them in treated ties so soon as spikes begin to wear loose. The life of the tie will be perhaps doubled at a fraction of its first cost. Special tools are used for preparing the tie and inserting the dowel.

CHAPTER V

BALLAST AND ROAD-BED

BALLAST

Uses and Materials. — Ballast is the material in which the ties are embedded. It spreads the loads over the more yielding earth of the road-bed, helps hold the track in place, and serves as a drain to carry away water from around the ties. It is cinders or gravel or burnt clay or furnace slag or broken stone, according to the amount of traffic, cost of the material, local conditions, and financial condition of the road. In ascending order of suitability the materials are about as named. Where no ballast is used, the tie is bedded in earth which is improperly called mud, dirt, or earth, ballast. Ballast is so called by reason of the early use in England for this purpose of the gravel brought by ships as ballast.

Requirement. — A good ballast material is free from dust, packs around the tie well, and yet drains itself quickly and thoroughly, leaving no water to soften it, to freeze, or to rot the tie.

Broken stone should be broken to pass through a 2-inch ring, better a 1½-inch ring, in all directions. Furnace slag should be similarly broken; gravel should be coarse, free from earth and fine sand, and without large stones. Gravel not naturally of this kind should be screened.

The ballast should not be less than 6 inches deep under the tie, is not usually more than 12 inches, and need not be more than 16 inches for the heaviest traffic.

Ballast that drains quickly, like broken stone, should be filled to the top of the tie throughout its length, and for a foot or so beyond the end, and then sloped down to the road-bed. Ballast that does not drain so well should be filled to the top of the tie

at the center and sloped or rounded to the bottom of the tie at the ends, and then sloped down to the road-bed. Sometimes such ballast is raised above the tie at the middle. It is doubtful if it is good practice to cover a portion of the tie with such material. In the arid West the practice may be good.

How Obtained. — Broken stone is usually purchased from contractors, but roads may own their own quarries and crushing plants. Gravel is usually obtained in gravel banks belonging to the road and worked by steam shovel, which loads directly from the bank to cars run onto a side track laid for the purpose. Slag is often furnished by furnace owners free on board cars at the furnace, the road doing the breaking and hauling. Cinders are obtained from the ash pits along the road and from mills and power plants adjacent to the line. Burnt earth, used mostly in the West, is obtained by burning clayey earth in kilns formed by piling wood — old ties or 4-foot fire-wood — in piles about 3 feet high and of the desired length, anything up to a mile, covering the pile with alternate layers of slack coal and earth, firing the wood, and slow burning it somewhat as in making charcoal.

ROAD-BED

Form. — Railroad road-bed, meaning the earthwork on which the ballast rests, is of various cross-sectional forms. What are

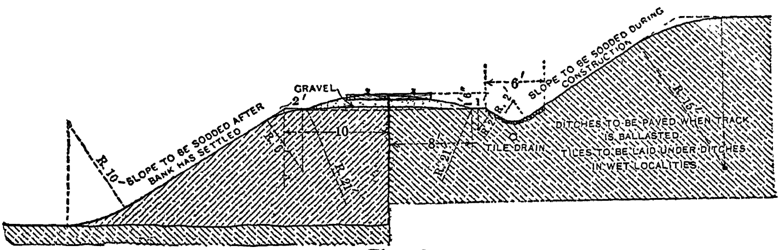


Fig. 18

probably the best forms for earth embankment and excavation are those suggested by Mr. D. J. Whittemore.*

These are shown in Fig. 18. Examples of the more common

* Trans. Am. Soc. C. E., Vol. XXXII, p. 255, September, 1894.

forms are shown in Fig. 19. The advantage of the Whittemore form is stability, the cross-section being that which will be naturally assumed by the earth if it is originally built in the more usual

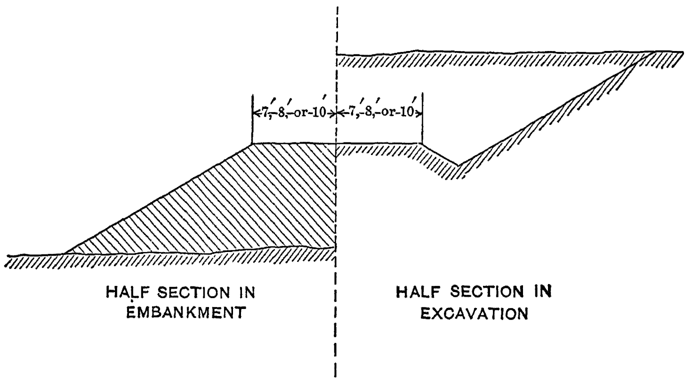


Fig. 19

form. To maintain the usual form with its sharp corners will require much more labor than to maintain the naturally rounded curves of the Whittemore section. Grassing is a material aid to maintenance. It costs something and may be omitted in the beginning if money is scarce and probable traffic doubtful, but it is probably worth all or more than it costs if it can be afforded.

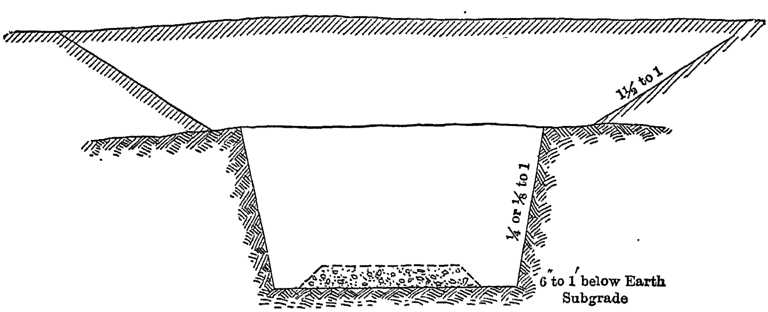


Fig. 20

An excavation in rock that is covered with a layer of earth is taken out as shown in Fig. 20, a berme or shelf being left between the foot of the earth slope and the top of the rock cutting.

Slopes. — The side slopes of the road-bed depend on the material of which it is made, the minimum slope insuring stability being used. With ordinary earth this is about 1 vertical on $1\frac{1}{2}$ horizontal. In American practice this slope is called "$1\frac{1}{2}$ to 1," the ratio of the horizontal to the vertical. Embankments of earth will rarely stand for even a brief period at a steeper slope, and are practically always made 1 on $1\frac{1}{2}$. The sides of earth excavation will stand for a time at steeper slopes, and for economy in first cost are frequently taken out at 1 to 1. This is unwise if the money for the better slope is available. The steeper slope insures an increased cost of maintenance, or, with inefficient maintenance, a poor track. The earth sloughs down, filling the ditches, thus obstructing the drainage, which softens the road-bed. Some sand and some wet clays require much flatter slopes, while rock embankments may be made as steep as 1 on 1. Rock excavations are usually taken out with vertical sides or a slope of 1 on $\frac{1}{4}$, and some dry clays and hard pans seem to stand best when cut down vertically. In any event, judgment is required to determine the slopes.

Ditches. — An excavation through earth sloping across the line of the road should be protected by a surface ditch on the higher side from 6 to 10 feet or more back from the edge of the cutting, running parallel with the excavation and discharging into adjacent hollows. Such ditches and the side ditches through the excavation should never be less than 1 foot deep, with rounded bottoms, and side slopes depending on the material. The top width will vary with the depth and side slope. Ditches should be given a grade of not less than 1 per cent. If the road-bed through the cut is level, the ditches may fall from the center toward each end; if the road-bed is on a grade, the ditches will fall for the most part with the road-bed. If the cut is long and the grade light, a portion of the ditch near the upper end may fall against the grade of the roadway.

Construction. — Across long level stretches of country a railroad road-bed will be in low embankment, thus providing thorough drainage and freedom from snow drifts. The material

for this embankment is usually obtained alongside from shallow ditches known as borrow pits. So far as possible these should be given a grade and opened to neighboring streams to provide drainage and prevent pools of stagnant water. If the subsoil is porous gravel, this matter will usually take care of itself. The borrow pits should not approach nearer than 6 feet to the foot of the bank, and the side next the bank should have a stable slope. The space between the foot of the bank and the edge of the pit is called a berme.*

The bank is best built in layers slightly higher at the sides than in the middle. It is not usual to remove the sod from the surface on which an embankment is to be placed, but sod or other perishable material should be excluded from the bank, particularly a low bank. The bank may be built by casting; that is, shoveled by hand from pit to bank, by drag scrapers, by wheel scrapers, or by grading machines, — the last named through prairie country being the most economical. Embankments made by casting or grading machines are loose, will settle considerably, and must be built from 10 to 15 per cent higher than the finished grade is to be. Embankments built with scrapers or wagons, and traveled by the teams drawing these tools, are more compact and will settle but little, an allowance of from 3 to 5 per cent probably being sufficient. Many very high embankments are of necessity made by dumping over the ends.

In hilly, rolling country the embankments will be made so far as possible from the adjacent excavations. When these are insufficient, the additional material necessary may be obtained from borrow pits alongside the embankments, but is better — though sometimes less cheaply — obtained by widening the excavations. It is desirable to have wide excavations, and undesirable to have undrained pits along the embankment. How to proceed in such cases depends on the available money. The occasional additional cost of using material from widened cuts is due to the

*Along a canal, the side opposite the tow-path is called the berme or berme side.

necessary longer haul. The price per cubic yard received by a contractor for grading is usually based on a specified limit of haul; if this limit is exceeded an additional price is paid for what is called overhaul. This is usually from $\frac{1}{2}$ to 1 cent per cubic yard per 100 feet overhauled.

CHAPTER VI

CULVERTS, BRIDGES, AND MINOR STRUCTURES

Structures Used. — When a stream is to be carried under a railroad one of the following structures is used: —

A blind drain for an insignificant spring or hollow.

A box or pipe culvert for a small stream or hollow where water may collect in time of storm or melting snow.

An opening, or stringer bridge, for an opening more than 4 feet and not exceeding 16 feet wide in low embankments. Such openings may also be used where the bank is too low for box or pipe culverts.

Arch culverts for similar openings or larger ones under high embankments.

Trestle bridges of wood for temporary structures across deep ravines, either dry or with streams in the bottom. As an average such trestles are cheaper in first cost than earth embankments with culverts when the height exceeds from 15 to 20 feet.

Trestle bridges of steel for permanent structures across deep ravines or gorges in mountain work.

Pile bridges for temporary and permanent structures across tidal estuaries, marshes, lakes, and moderate size, soft-bottom, sluggish streams.

Girder bridges for openings of one or more spans from 16 to 75 feet, either for stream or road crossings.

Truss bridges for openings of one or more spans over 75 feet. These limits of length are not absolute. Girder bridges are built of more than 100-foot spans, and truss bridges occasionally less than 75 feet.

When a cattle pass is to be built under a railroad the usual form is a stringer opening.

When a highway is carried across a railroad at grade a road-

crossing is required; and if the highway is in the country where stock is likely to be driven, cattle guards are required. Cattle guards and road crossings will be used for a number of years to come, but will eventually disappear with the abolition of all grade crossings.

CULVERTS

Blind Drains. — A blind drain consists of cobble or large broken stones, carefully laid so that water in small quantities can find its way between them and thus under the bank. A better construction for the same purpose is a line of vitrified earthen pipe or cast-iron pipe, from 4 inches to 1 foot in diameter, laid with head walls of rough masonry or concrete at the ends.

Wood Box Culverts. — Box culverts are built of wood or stone; of wood in new construction under low embankments where stone

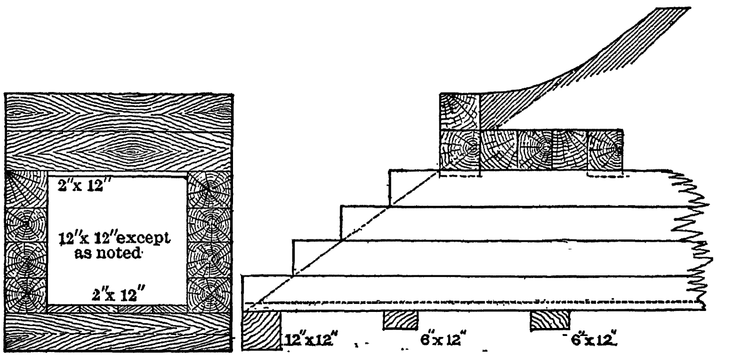


Fig. 21

is very expensive, wood cheap, and the item of first cost an important one. Wood culverts consist of rectangular boxes as long as the width of the bottom of the embankment, and are usually built of heavy timbers, as shown in the plan, Fig. 21. A portion of the cover timbers are notched down to hold the sides apart, or planks are nailed to the under side of some of the cover sticks. The timbers are fastened together with drift bolts or boat spikes. Drift bolts are simply long pieces of round or square iron, some-

times pointed, and with or without heads. Boat spikes are square-sectioned, long, chisel-pointed nails, forged rather than cut. Drift bolts are usually driven into holes bored for them. Boat spikes may be driven without boring, but the boring is sometimes done.

Very cheap, small box culverts of 1 or 2 square feet in section, may be built of 2- to 3-inch plank, the sides being planks on edge and the top and bottom short pieces nailed across. Such structures may be built for temporary use, but are not advised for stream crossings. They may be used for side drainage where failure and replacing does not interfere with the track.

Stone Box Culverts. — Stone box culvert walls are built of rough, flat stone, the paving is of cobbles or broken stone on end, and the covers of large thick stone. The walls and ends should be laid in cement mortar, the paving-stones carefully laid close together and grouted with cement grout. The length is determined by the width of embankment, and should be such that at the natural slope the earth will fall around the end walls not quite to the opening, and should reach the top back edge of the parapet wall.

Such culverts are practically never built where the span is more than 4 feet, owing to the difficulty of securing and handling stones of sufficient size and strength for the covers; but double boxes are sometimes built.

The side walls are sometimes stepped down at the slope of the bank.

The box culvert is not now much built, the pipe culvert with concrete end walls, or the concrete barrel culvert taking its place. Some wide box culverts are built with old rail and concrete covers.

Pipe Culverts. — A pipe culvert consists of one or more lines of vitrified earthen pipe or cast-iron pipe, with head walls of masonry at the ends. The masonry is rubble or concrete. Vitrified pipe may be had in lengths of from 2 to 3 feet, and in diameters from 4 to 36 inches. Cast-iron pipe is ordinary water pipe for low pressure under low embankments, and for

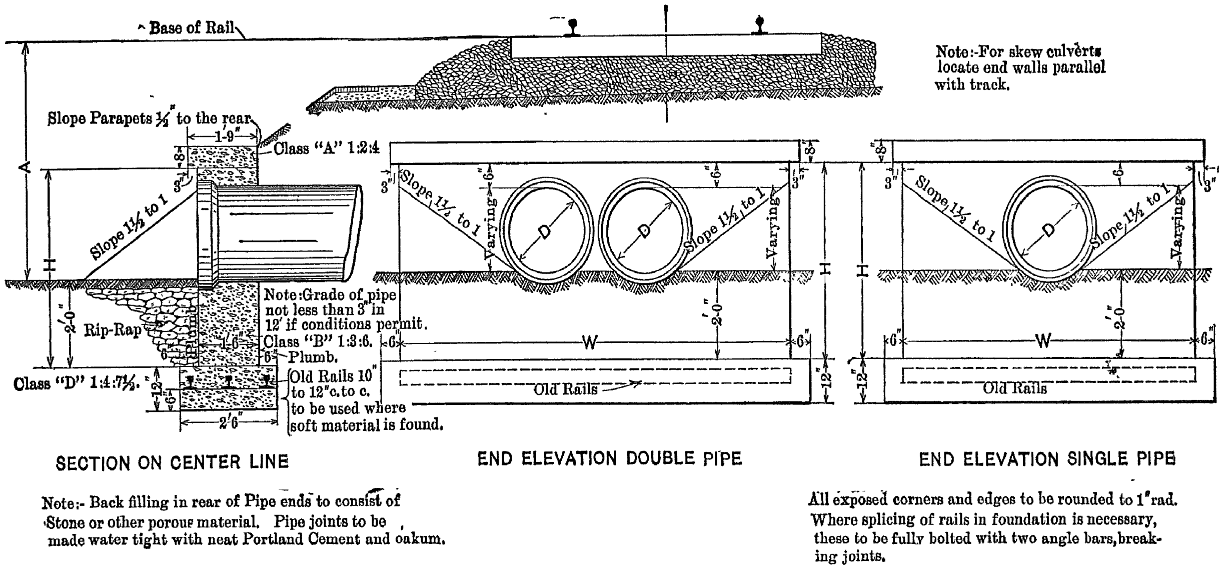


Fig. 22. N. Y. C. & H. R. R. R. Standard Pipe Culvert

high pressure under high embankments. It is made in lengths of 12 feet, and should be coated with the usual preservative coating. The lengths may be cut to meet the requirements of any embankment. The pipe should be firmly embedded in the original ground, or in a prepared foundation, if the original ground is not sufficiently solid, and the head walls given a good foundation well below the pipe. The joints should be packed with oakum or hemp yarn and cement mortar.

Circular concrete culverts have been recently built with success, and may often be used where gravel is cheap. Designs for vitrified pipe and concrete culverts are shown in the figures. (Figs. 22, 23, and 24.)

Arch Culverts. — Arch culverts, single or multiple, require much care in design, and it would be foreign to the purpose of this book to go into the theory of the design of these openings. A general plan for moderate spans is shown in Fig. 25. Reinforced concrete arches are rapidly replacing masonry arches. The wing walls are usually flared on the up-stream end, and may be either flared or straight on the down-stream end. The length of culvert is governed by the height of bank, the slope of which should just catch the upper back edge of the parapet stone or wall, and should follow down the slope of the wing walls.

Openings. — An opening, open culvert, or stringer bridge, consists of two abutments, which are designed as retaining walls, on top of each of which lies a plank, 3 by 12 inches, called a wall plate, on which rest the ends of the stringers that carry the track. The abutments are either carried out straight (in which case they are as long as the embankment is wide at the base), or the portion outside of the road-bed is turned at an angle of 120 to 135 degrees, as shown in Fig. 28, page 74. These wing walls, or straight end walls, are either sloped down with the embankment or are stepped down. If of masonry, they are usually stepped; if of concrete, they are perhaps generally sloped.

When built of masonry the abutments are of random range masonry with rubble backing; are not less than 3 feet thick at the top, and at the bottom not less than $\frac{4}{10}$ of the height. The

safer rule is to make the bottom thickness half the height. The wing walls need not be more than $2\frac{1}{2}$ feet thick on top. The front

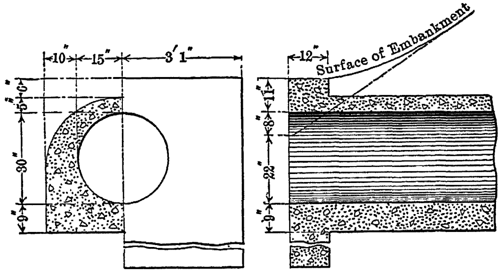


Fig. 23

walls may be vertical or battered 1 inch to the foot. The back of the wall may be stepped or battered, but should never be ver-

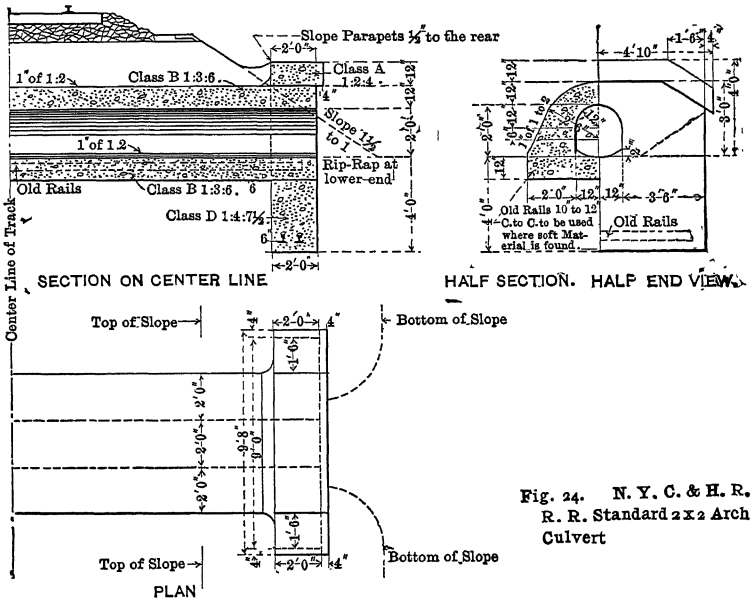


Fig. 24. N. Y. C. & H. R. R. R. Standard 2 x 2 Arch Culvert

tical. A portion of the wall may be carried up above the bridge seat to hold the ballast, or an end plank may be used at the ends

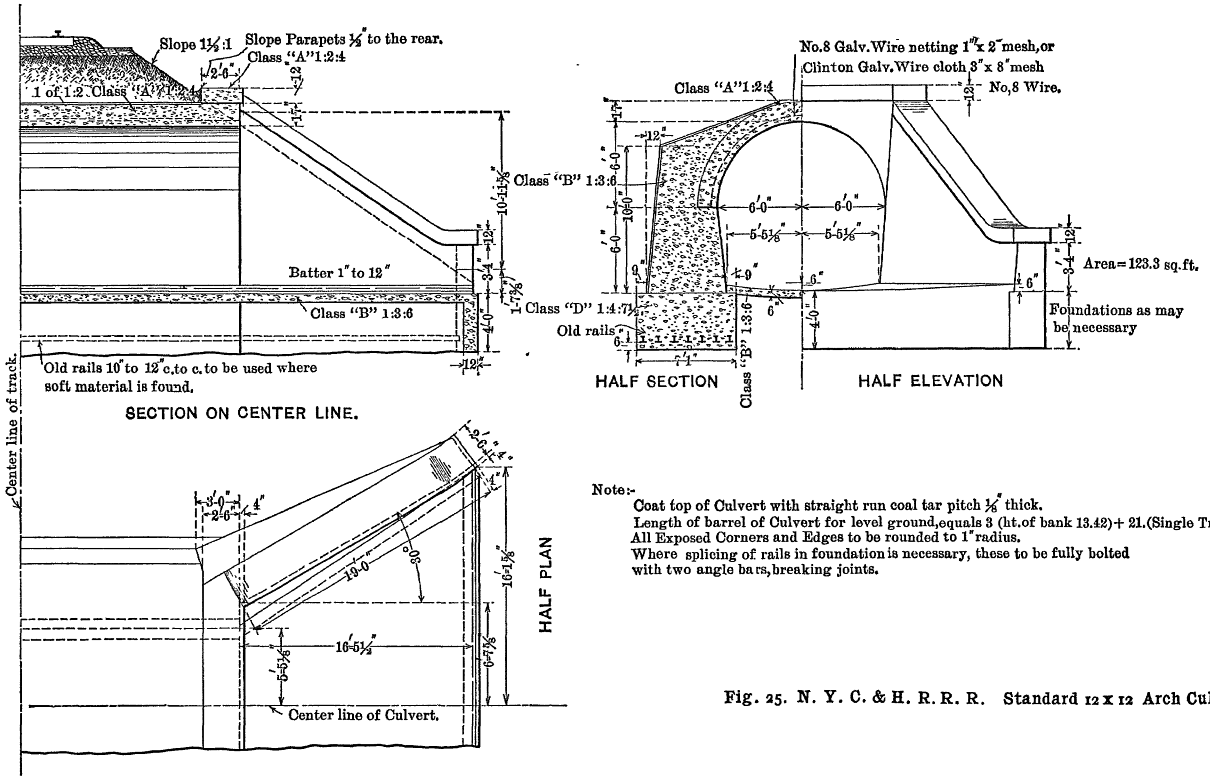


Fig. 25. N. Y. C. & H. R. R. R. Standard 12 x 12 Arch Culvert

Note:-

Coat top of Culvert with straight run coal tar pitch ⅛" thick.
Length of barrel of Culvert for level ground, equals 3 (ht. of bank 13.42) + 21. (Single Track).
All Exposed Corners and Edges to be rounded to 1" radius.
Where splicing of rails in foundation is necessary, these to be fully bolted with two angle bars, breaking joints.

of the stringers. Coping stones should be used 1 foot thick, projecting from 3 to 6 inches beyond the face of the wall.

Concrete is now much used for all classes of railroad masonry. The closest attention to materials, proportions, and manipulation is necessary to good work; but, when properly made, concrete forms an excellent substitute for masonry walls. It is usually cheaper, principally because it may be built by unskilled labor. It is doubtful if it ever presents quite so good an appearance as first-class stone masonry, and while unquestionably very durable, it is yet to be proven that it is as durable as stone masonry. In combination with steel reinforcing bars it may be used with economy for very flat arch bridges, often in places where head room is insufficient for a high arch, and not infrequently the arch form is entirely omitted, the covers of culverts of considerable width being made perfectly flat.

For cheap, hasty construction, piles may be used for the abutments of stringer openings. They will be backed with 3-inch plank to hold the embankment, and may be sheathed with plank on the stream side. They will be of sizes and forms mentioned later under trestle bridges, and will be capped with 12- by 12-inch caps to carry the stringers. A double row of piles placed $2\frac{1}{2}$ to 3 feet apart may be necessary if the embankment is high.

The stringers will vary in size according to the span. The span should be so fixed that commercial lengths of timber will fit. The usual stringer section for openings of from 14 to 16 feet is 8 by 16 inches, while 7 by 16 inches and 10 by 16 inches are not uncommon. Four, six, or eight stringers may be used. When there are four stringers, they are placed in two double rows spaced 5 feet apart center to center, each double row being spread by $1\frac{1}{2}$- to 4-inch wood packing blocks, or cast-iron packing washers, and held together by machine bolts, $\frac{3}{4}$ to $\frac{7}{8}$ inch in diameter, and accompanying washers. The stringers may be held to line on the abutment by a filler plank spiked to the wall plate. When six stringers are used the additional stringers may be placed 3 feet from the center of the double row to the outside of outside

stringer, or two rows of three stringers each, the stringers of each row being separated by packing blocks or washers, may be laid with the middle stringers of the two rows 5 feet apart, center to center, as shown in Fig. 27. These exact dimensions are not invariable. Eight stringers are usually in two sets of four.

Sawn bridge ties 6 inches by 8 inches by 12 feet, spaced from 4 to 8 inches in the clear, are laid on the stringers, and sometimes notched or dapped on them 1 inch. Guard rails are placed on the ties, and also notched or dapped 1 inch. These guard rails are placed outside the track rails; and if outside stringers are used, should be placed over them. They should be of 6- by 8-inch stuff, bolted through tie and stringer at every fourth to eighth tie, and spiked with boat spikes to the remaining ties.

Estimates of cost are made by estimating the lumber, including the ties, by the thousand feet, board measure, at an assumed or known price per thousand in place; and the spikes, bolts, etc., are estimated by the pound.

Permanent openings having steel **I** beams for stringers, with buckle, trough or plain plates, supporting ballast in which the ties are laid, is a type of opening expensive in first cost, but gaining in favor, as indeed is the solid ballasted floor for all ordinary railroad bridges.

Area of Water Way. — The area of water way required in a culvert depends on, 1. Maximum rate and duration of rainfall. 2. Character of drainage area tributary to the culvert. In character of drainage area is included the vegetation, the soil, the size, the inclination, and the shape. A steep, short, amphitheater-like area will deliver its water quickly and from all parts at once, while a flat and much elongated area will deliver its water more slowly, and the delivery for the whole area for a given storm will not reach a given point at one instant.

The flow from a deep-soiled and timbered area will be more regular than from a rocky, barren area, which will yield a flashy flow, very large in time of storm or melting snow, very small in periods of dry weather.

The judgment must be used in determining the necessary

water way. The judgment will be aided by Myer's or Talbot's formula. The former is,

Area of water way in square feet $= C\sqrt{\text{Drainage Area, in Acres}}$; the latter is,

Area of water way in square feet $= C\sqrt[4]{(\text{Drainage Area, in Acres})^3}$.

The first is said to give too large water way for small drainage areas, and the second gives water ways that will mean occasional discharge under a head — the water backing up till the necessary head has been obtained.

The C of both formulas is a variable coefficient depending on the characteristics of the drainage area. For Myer's formula C varies as follows: For gently rolling prairie $C = 1$; for hilly ground, 1.5; and for mountainous and rocky ground, 4. No account is taken of the shape of the drainage area, which should be allowed for in the coefficient. For Talbot's formula, C may be taken as follows: For steep and rocky ground, $\frac{2}{3}$ to 1; for rolling agricultural country subject to floods from melting snow, and of valley lengths of three or four times their widths, $\frac{1}{3} \pm$ (plus for a short valley, minus for a long one); for very long valleys and no accumulating snows, $\frac{1}{5}$ to $\frac{1}{6}$ or less.

TRESTLES AND PILE BRIDGES

Trestles. — A trestle bridge consists of a floor system like that for stringer bridges resting on trestle bents instead of retaining wall abutments and piers. The bent for single track consists of a sill, on which rest four posts, two vertical or plumb posts, and two batter posts. These posts carry a cap. The sill rests on a foundation consisting of one or more mud sills of 6- by 12-inch plank under each post, or masonry piers solid throughout the length of the sill, or separate under each post, or on piles. Solid masonry piers are used on solid ground, and piles where the ground is soft for a considerable depth. The height of the bent is from the top of the cap to the bottom of the sill. The batter posts have a rake or batter of 3 inches to the foot or less. The length of the sill depends on the height of the bent. The

posts may be mortised into the sills and cap, and treenails used; they may be notched and drift bolted, or drift bolted alone; they may be doweled; they may be joined by splice pieces on the side, making a "plaster" joint; special iron-joint plates may be used, or split caps and sills. The last two methods are the most modern and approved.

Sway bracing, one plank diagonally on each side of the bent, should be 3 by 10 inches, or 3 by 12 inches, bolted or spiked to

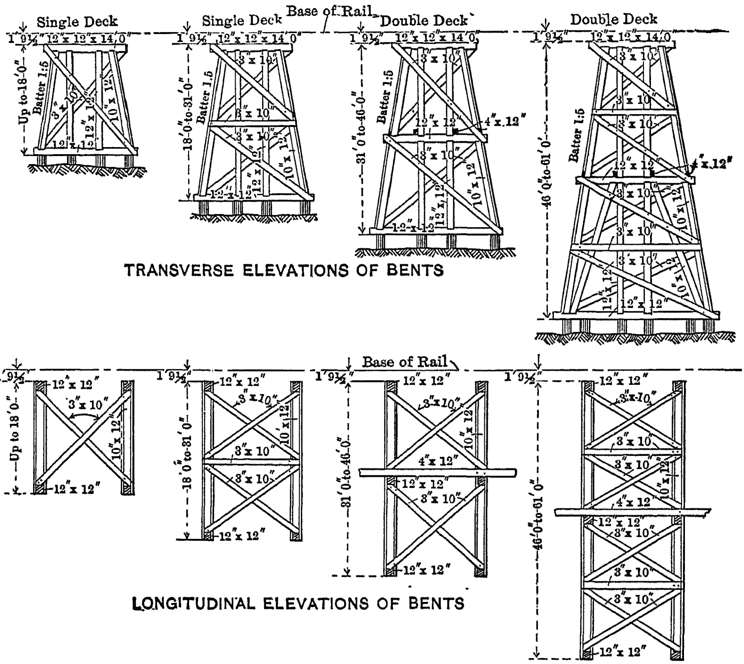


Fig. 26. Trestle Bents

the cap, each post, and the sill. It is not absolutely necessary that they should extend over the caps and sills, but it is better that they should.

When the bents exceed 18 to 30 feet in height they are made in two parts, and the bridge is known as a double-deck bridge. If the height is greater than 40 to 50 feet, special designs are used.

For the ordinary double-deck bent the lines of the posts are kept continuous, the intermediate horizontal piece being sill for the upper story and cap for the lower story. Longitudinal bracing of various forms is introduced, to give longitudinal stability to the bridge as a whole.

The stringers may rest on the caps with filling blocks or brackets to keep them in place, or they may be drift bolted to the caps. The use of corbels is not recommended.

When trestle bridges occur on curves, the best way of providing for the cant of the track is to frame the posts to unequal lengths so that the cap has the proper slope, or to dip the entire bent, sloping the foundation.

Trestles vary in the details of their design, but standard dimensions of principal parts are indicated on plans shown in Fig. 26 and may be adopted for ordinary structures. For special structures or unusual loading the dimensions and arrangement of the members must be designed in accordance with the general principles of bridge design.*

Pile Bridges. — Pile bridges have the same floor system as trestle bridges, and differ from these only in that pile bents are used instead of framed trestle bents. For ordinary single-track bridges four piles not less than 12 to 14 inches under the bark at the butt are driven 4 feet apart on centers, or 5 feet for the center space and 3½ feet for the outer space. That the load may come directly over the two center piles the spacing should be about 4 feet 10½ inches for the center piles, and this spacing is sometimes adopted. The piles are capped with either a split cap, as in framed bents, or a solid 12-inch by 12-inch by 14-foot cap drift bolted down. The drift bolts should be about ⅞ by 20 inches. Sway bracing is used as in framed bents. The side piles are sometimes driven with a batter, but this is not

* For these principles and for special floor systems Foster's "Wooden Trestle Bridges" may be consulted, and for the design of steel trestles or viaducts, which are unusual structures requiring special treatment, Johnson, Bryan, and Turneaure's "Framed Structures," or Merriman and Jacoby's "Bridges," may be used.

necessary. The piles should be peeled before driving. The N. Y. C. & H. R. R. R. standard pile bridge is shown in Fig. 27.

There are various rules for determining when a pile is sufficiently driven. All of these rules or formulas have empirical constants, and are based on the supposition that the work done by the descending pile against the resistance of the surrounding earth at a single stroke of the driving hammer equals the work done by that hammer in its fall. Theoretically, the pile should be driven until the determined earth resistance with the proper safety factor equals the pressure likely to come upon the pile. Where the depth of comparatively soft soil is so great that piles may seemingly be driven indefinitely, perhaps one of these rules may be used, and what is known as the *Engineering News* formula is given. It is:

$$\text{Safe load} = \frac{2\,wh}{s + 1},$$

in which w is the weight of the hammer in pounds, h is the fall in feet, and s the penetration of the pile in inches under the last blow. The arbitrary constant 1, added to s, is to allow for the settling of the earth around the pile between blows; where the blows are rapid, as in the steam driver, the arbitrary constant may be reduced to $\frac{1}{10}$.

But under ordinary circumstances piles may be driven to refusal, oftentimes in very deep and comparatively soft soil, under the blow of a 2000-pound hammer dropping 20 feet. The desired minimum penetration of a pile for a blow of the hammer may not be realized so long as the driving is continued; but if the driving be discontinued for a time, the set of the materials around the pile seems to give additional supporting force, and the piles may be safe, though not realizing the full requirements of the formulas. The engineer should not accept such pile driving unless experience in the vicinity has taught him its safety. If rock is known to be within reach of ordinary pile lengths, the driving should be to the rock, but care should be taken not to drive the pile after it has reached the rock. It is usually economy

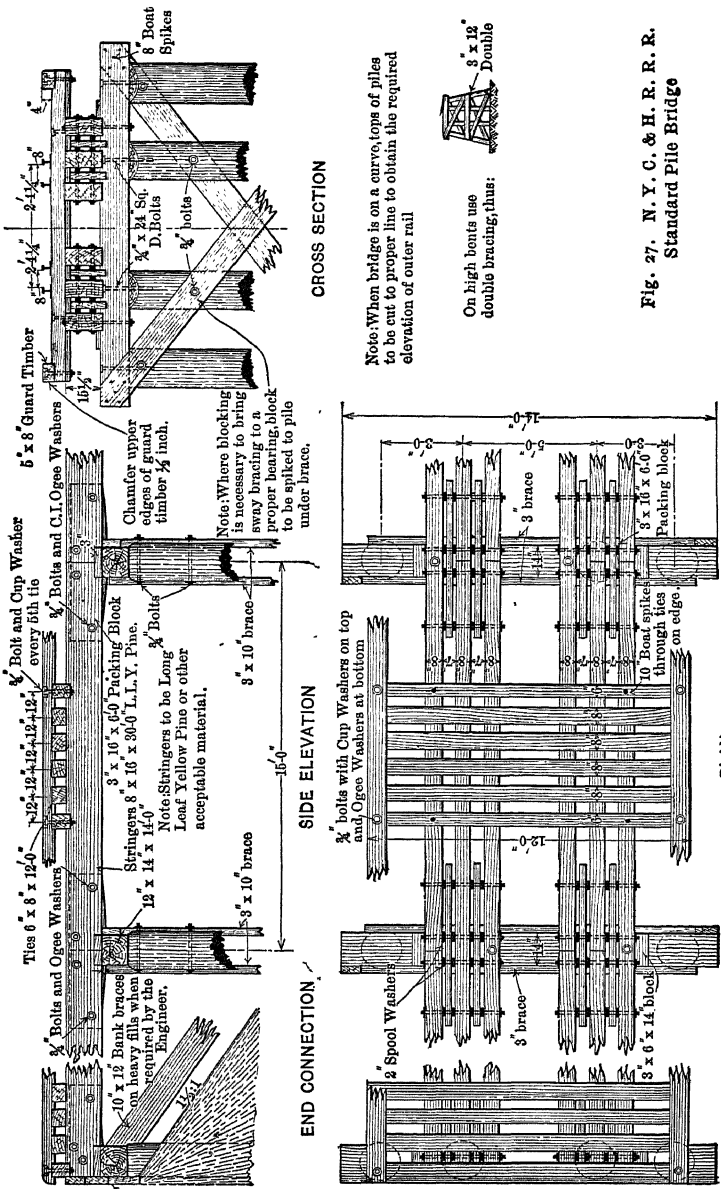


Fig. 27. N. Y. C. & H. R. R. R. Standard Pile Bridge

in driving to use a hammer in which the hammer is not tripped, but carries the rope down with it; but the test blow should be made with a hammer that trips, since a better blow is thus insured.

Piles are cut off at the proper level to receive the cap. If badly broomed or split, the pile must be drawn and another driven. In determining the lengths of piles some allowance for brooming must be made. The butts are uusally beveled off, and frequently a rim of iron is driven on to prevent brooming and splitting.

Piles are purchased by the lineal foot, and the driving is paid for by the lineal foot driven. Careful examination should be made of the site of a pile bridge by sounding with gas-pipe rods or boring tools, in order that piles of the proper length may be ordered. In specifying dimensions of piling it is well to demand piles not less than 12 inches in diameter under the bark in the middle, rather than some definite size at the butt, that the taper shall be uniform and the point not less than 10 inches in diameter.

For pile bridges on curves, the piles are cut off at unequal heights to give the proper slope to the cap.

Timber for Trestles and Pile Bridges. — For the stringers and ties of trestle or pile bridges, southern long leaf pine, Douglas fir, commonly known as Oregon pine, or a good white oak are suitable; for piles, any of these timbers, or spruce. Good white pine or spruce will answer for caps, guard rails, sway bracing, packing blocks, etc., but not infrequently oak is as easily obtained and is of course preferable.

Timber, except in piling, is estimated by the thousand feet, board measure, in place in the structure, which usually means including the iron, which is estimated by the pound.

Concrete Pile Foundation. — A late type of pile for foundation for trestles or bridge masonry is the concrete pile made in place by driving a collapsible steel tube, withdrawing it and filling the hole with concrete, or made with reinforcing bars of steel to be driven as wooden piles are driven.

Screw Piles. — For some special structures screw piles are used. These consist of a central shaft with a very broad thread, usually

made of cast iron and sunk by twisting into the soil. These piles may be several feet in outside diameter and are but infrequently used where there is great depth of comparatively soft bottom.

GIRDER AND TRUSS BRIDGES.*

In reading what follows it must be understood that practice varies considerably on either side of the mean figures given, according to the judgment of the designing engineer, the money available, and the special requirements of the site of the structure.

The Masonry. — For double-track bridges the best form of abutment is a wing wall retaining wall. The main wall will be from 4 to 6 feet thick under the coping, and will have a thickness of not less than 0.4 the height at any point below. The footing courses will be 15 to 18 inches thick, and will project from 6 inches to 1 foot beyond the base of the wall. The same projection pertains to whatever sort of foundation must be built below the footing course. In a stream the top of the footing course should not be above low water. The back portion of the wall is carried up in what is called a parapet wall to retain the ballast, and single large square stones may be laid on the coping for bridge seats. Piers will be from 18 to 22 feet long by from 5 to 7 feet thick under the coping, which will be from 12 to 24 inches thick. The piers will be battered, and on the up-stream side will have an ice nose, as shown in Fig 29. Where no ice forms the up-stream end may be rounded, and the best looking pier is one in which above high water both ends are rounded. These piers, if of masonry, should be built of first-class masonry; many are now built of concrete.

Another form of pier consists of steel cylinders sunk in the river around a cluster of piles and filled with concrete. One cylinder is used for each truss, and the two connected with lateral

* It is no part of the purpose of this book to take up the subject of bridge design, but some general statements are given to assist the beginner in selecting a type of bridge and to estimate its cost.

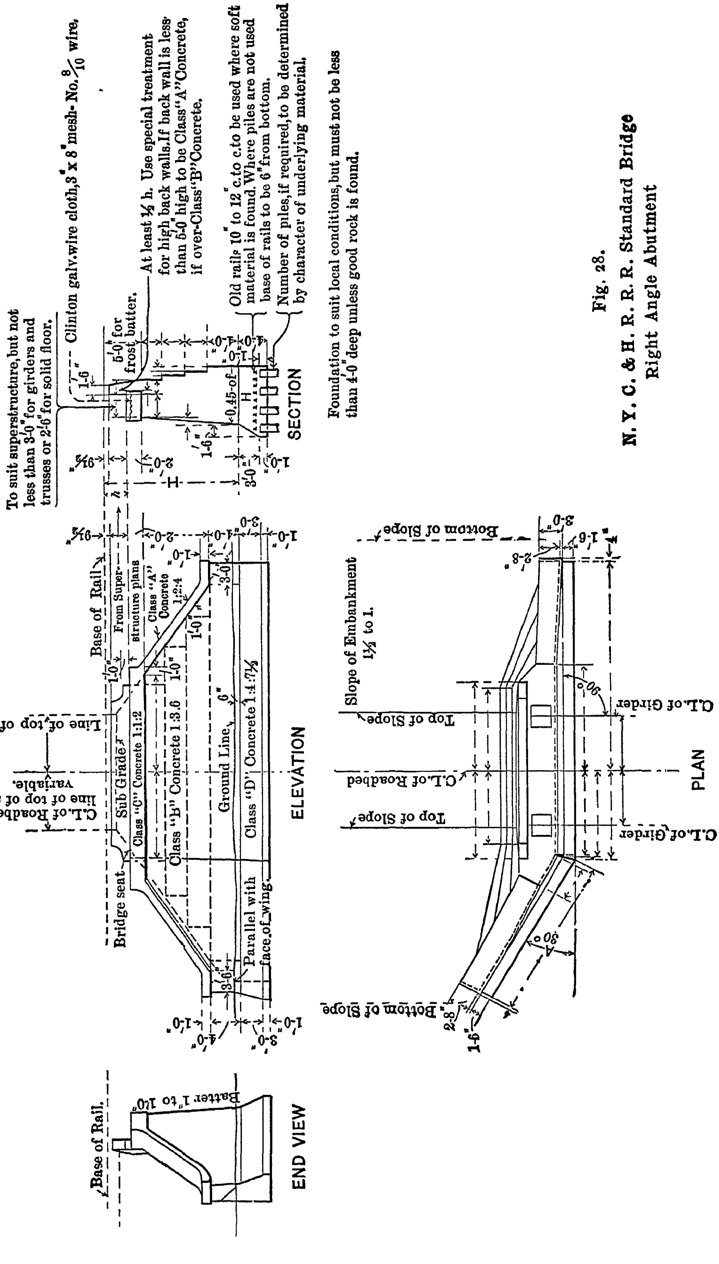


Fig. 28.
N. Y. C. & H. R. R. R. Standard Bridge
Right Angle Abutment

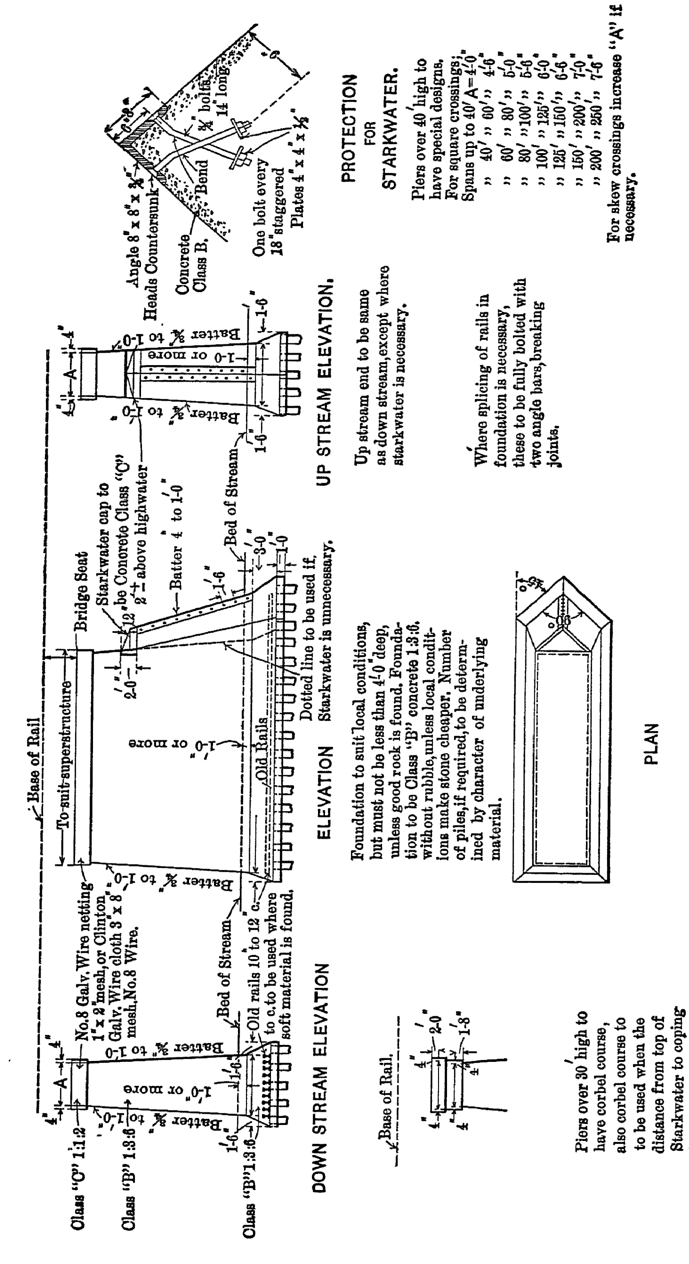


Fig. 29. N. Y. C. & H. R. R. R. Standard Piers

bracing of plates or angles. Such piers may be used where there is considerable depth of firm bottom to hold the pier against flood and ice, and when the necessary bottom is wanting the cylinders may be bedded in a cribwork filled with stone or concrete.

For temporary wooden bridges in new country, pile abutments and piers may be used.

Superstructure. — For short spans, or where more than one span is required, a deck bridge is economy if there is head room for the necessary water way. The depth of the truss or girder will be from $\frac{1}{10}$ to $\frac{1}{9}$ of the span. For spans under 20 feet rolled I beams may be used; between 20 and 100 feet, plate girders; between 100 and 250 feet, riveted lattice girders; over 250 feet, pin connected trusses. These figures represent about average present practice, but there is a strong tendency to make all but very long trusses of the riveted type, which, while more costly, are stiff. For very long spans, 500 to over 600 feet, the cantilever, steel arch, and suspension bridges are the types to use.

Bridge Weights. — The weights of steel in the various forms of bridges may be estimated with sufficient precision from the following formula taken from Johnson, Bryan, and Turneaure's "Framed Structures." In these formulas W is the total weight of the span of length l, but in plate girders l is the length over all.

PLATE GIRDERS		
Deck plate girder	$W=$	$12l^2 + 150l$
Through plate girder, iron floor system	$W=$	$12l^2 + 500l$
Through plate girder, large ties on shelf or flange angles	$W=$	$9\frac{1}{4}l^2 + 150l$
Through plate girder, solid iron floor	$W=$	$12l^2 + 800l$
RIVETED LATTICE BRIDGES		
Deck bridge, cross-ties on top chord	$W=$	$7l^2 + 200l$
Through bridge, iron floor system	$W=$	$7l^2 + 300l$
PIN CONNECTED BRIDGES		
Deck span, cross-ties on top chord	$W=$	$5l^2 + 250l$
Deck span, iron floor system	$W=$	$5l^2 + 475l$
Through span, iron floor system	$W=$	$7l^2 + 650l$

Economical Spans. — The most economical length of span to use for a bridge of several spans is usually stated to be that length which makes the cost of the substructure equal to that of the superstructure. This is doubtless about true. If the piers are of equal cost, the theoretically most economical length of span is found from the following formula, in which C is the cost of a single pier in dollars; p is the cost per pound of the iron in cents; a is the coefficient of the l^2 term in the bridge weight formula; L is the total length of the bridge in feet; and x is the most economical number of spans:

$$l = \frac{L}{x} = \sqrt{\frac{100\,C}{ap}}.$$

The most economical length of span may not always be used. When the rock bottom of a small river, crossed at low height, makes piers very cheap, the most economical span becomes so small that the river would be filled with piers, obstructing the water way, and sometimes in important navigable waters no piers are permissible. Judgment must be used to determine what shall be done. Area of water way should be determined by investigations of high water, both from marks and inquiries of old residents.

MISCELLANEOUS MINOR STRUCTURES

Road Crossings. — Road crossings are formed by laying planks 3 or 4 inches in thickness on filling pieces of sufficient thickness to bring the surface of the planks to the level of the rail top, or slightly below it. The filling pieces and plank are spiked to the ties. One plank is usually laid outside the rails on each side and four planks between the rails, leaving a flange way next the rail and open joints filled with the ballast on which the planks are bedded, between planks. The approach to the road crossing consists of a graded roadway of such dimensions as may be necessitated by the difference in level of the track and intersecting roadway and the importance of the road. Road crossings at grade will be eventually abolished.

Cattle Guards. — A cattle guard is a structure intended to prevent cattle passing from a highway crossing to the right of way of the railroad. It should be so designed as to make the passage so difficult or unpleasant that no hoofed animal will cross it, and yet it must not catch the animal and hold it if it attempts to make the crossing. The modern form of guard is a surface guard, one

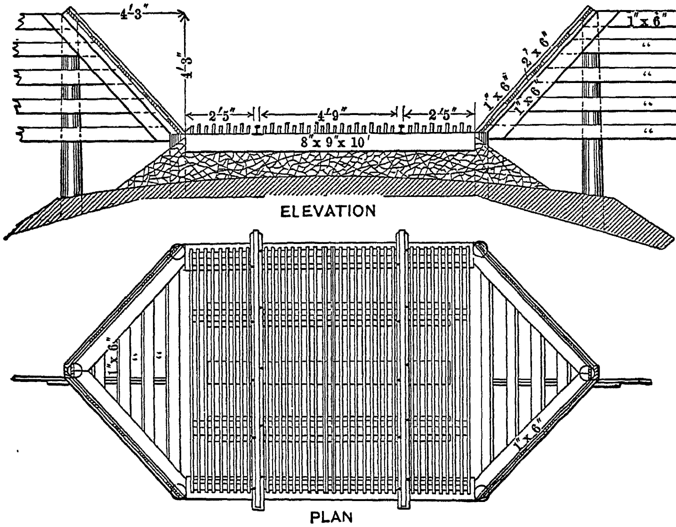


Fig. 30. Surface Cattle Guard

form of which is shown in the figure. The type is called surface guard to distinguish it from the older common type of pit guard, which was a pit about 2 feet deep crossed by the rails on stringers, and otherwise open on top or partly covered by triangular slats.

Sections of fence lengthwise of the track and resting at an inclination on the ends of the cross or wing fences serve to keep small stock from getting around the ends of the wing fences. Cattle guards will disappear with the abolition of grade crossings.

Fences. — The right of way of American railroads is fenced between stations, but as a rule not within the limits of any town or city. The fence serves only to mark the boundaries of the right of way and to keep cattle from the tracks. It is not designed

to be effective in keeping men from trespassing. An effective fence and police service would prevent probably two thirds the deaths now due to operation of trains, and would do much to eliminate the common tramp. It is generally supposed that American roads cannot afford this adequate protection. It will probably be recognized eventually as a necessity.

For present recognized needs, the best fence is a galvanized wire fence 4½ feet high, of about nine strands, close spaced near the bottom to turn small animals. The vertical stay wires are spaced 12 inches apart and the horizontal wires, 3, 4, 5, 6, 7, 8, 9, and 9 inches. Barbed wire should not be used. The posts may be cedar, chestnut, black locust, or other durable wood. They should have a minimum section equal to the area of a circle of 4 inches diameter, and should be 8 feet long. They should be spaced from 16½ to 33 feet apart, according to the character of the ground and the service likely to be required, and set not less than 3 feet in the ground where this is practicable. End posts and gate posts are larger and longer, should be set not less than 4 feet in the ground, and thoroughly braced against the pull of the fence and the cross strain of the opened gate. The wire is usually strung on the side of the posts away from the track, except on curves, where it is so placed as to put the wire strain against the post.

CHAPTER VII

TURNOUTS

General Form. — When one track branches from another, it does so by what is called a turnout. The change from main track to turnout is accomplished by introducing two movable rails, either both main line rails (stub switch), one main line rail and one turnout rail (split switch), or both turnout rails (Wharton safety switch).

Stub Switch. — The stub switch is shown in Fig. 31. The movable main line rails PH and AB are called switch rails. These rails are moved at H and B from main line to turnout and back by means of a lever L connected to the rails by rods. The rails themselves are held together by tie rods. The outer rail and the turnout curve of the main line rail cross at F, at which point what is called a frog is introduced to provide channels for the passage of the wheel flanges across the intersecting rails. The switch rails are spiked to the ties for a part of their length from P and A toward H and B, so that when pulled over at H and B to the turnout rail ends they bend to an elastic curve which in calculations is assumed to be a circular arc of radius equal to that of the turnout curve, and the free length of switch rail is computed on this supposition. The distance moved at H and B is known as the throw. Guard rails G are placed opposite the frog to hold the wheels close against the rail opposite the frog, to guard against the possibility of the flange of the wheel next the frog striking its point and running up on it with danger of derailment. These guard rails are used whatever the form of switch,

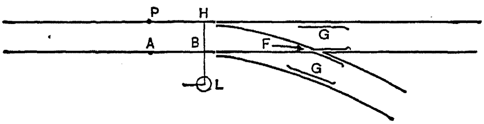


Fig. 31

but there are frogs not in common use designed to make them unnecessary.

The stub switch is introduced temporarily, or in unimportant track.

Split Switch. — The split switch is the common standard, but there are various forms of it. In the ordinary form, shown in Fig. 32, one main line rail and one turnout rail are continuous. The switch rails HP and AB swing about P and B and are beveled at the points H and A so that when HP is thrown against the main line rail it will lie close up at the point H, as will AB at the point A when thrown against the turnout rail to make continuous main line. When in the position shown in the figure, the switch rails are set for the main line. To set them for the turnout they are thrown over at H and A till the point H lies against the main line rail and forms with it an acute angle called the switch angle. The turnout curve is tangent to the switch rail at P and to the frog at its toe end a little to the left of F, the frog being straight throughout its length.

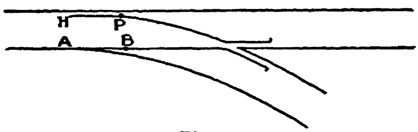


Fig. 32

The switch rail is of various lengths. For weights of rail under 65 pounds a switch rail 15 feet long with $5\frac{1}{4}$ or $5\frac{3}{8}$ inches spread at the heel P, will answer; but for heavier sections a wider spread must be had because of the wider base and the necessity for heavier fastenings, and hence a longer rail is required to keep the switch angle small. The common lengths are 14, 15, 18, 20, and 24 feet, although the last two are somewhat exceptional. For yard use, where speed is slow and space cramped, switch points — as switch rails are frequently called — of $7\frac{1}{2}$, 10, and 12 feet are in common use. It is not customary to curve the switch rail, but a few elevated and subway roads have such curved points. This practice necessitates carrying both right and left hand points and the use of short radii or long switch points.

Switch Parts. — In the two general classes of switches shown, the movable end is called the point of switch, the fixed end the

heel of switch, and the length of the movable rail the length of switch. At the point of switch there is always an extra large and long tie, sometimes two, which supports the movable points and adjacent rails, and to which the lever for working the switch is fastened. This tie is called the head-block. The distance from head-block to the point of frog, measured by some makers along the straight rail and by others along the curved rail, is called the lead. Probably, technically, the distance along the curved rail is the lead, and the distance along the straight rail would better be known as the frog distance.

A standard form of split switch is shown in Fig. 33. The plates shown at 1, 2, 3, 4, 5, and 6 are called friction plates, and the

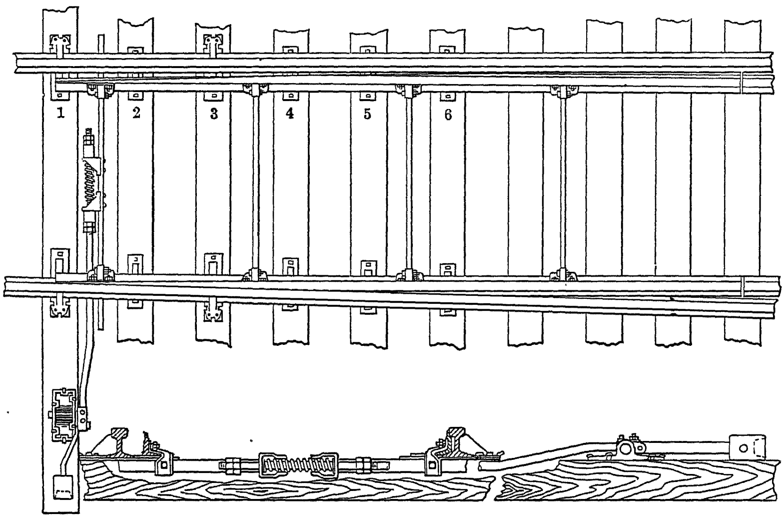


Fig. 33. Split Switch

four pieces at and opposite 1 and 3 are called rail braces. This switch is frequently made partially automatic by a spring arrangement attached to the first connecting-rod, called the head rod, by means of which, unless the switch is thrown open by the lever, it is kept set in the main line, but the train may enter the main line from the siding, since the flanges of the wheels will throw the switch against the spring, which will return the movable

points to place at once after the wheels have passed. One method of arrangement is shown in Fig. 33.

A switch is a facing-point switch to trains traveling the main track in the direction switch — frog, and a trailing-point switch to trains traveling the main track in the direction frog — switch. The latter are the safer.

The Wharton Safety Switch. — This switch provides for a continuous main line. It is a split switch, but with movable rails in the turnout instead of the main line, the wheels being lifted on an incline so that the flange will cross over the main line rail. Although adopted to some extent, this switch is not in common use.

Frogs. — Frogs were formerly made quite short and of cast iron with steel points and top plates. They are now almost altogether made of rail of the same pattern as that used on the main

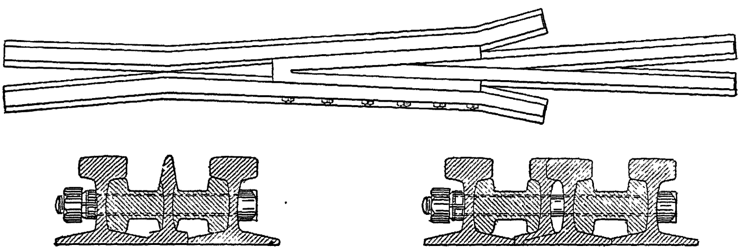


Fig. 34

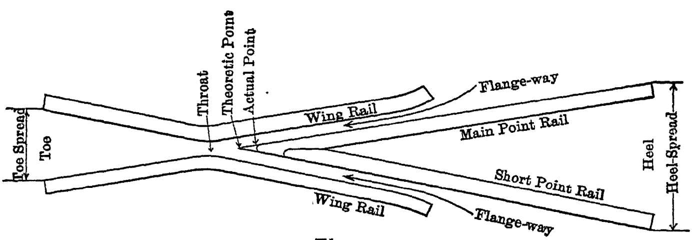


Fig. 35

line of the road. There are two general classes, stiff frogs and spring rail frogs. One ordinary form of stiff frog is shown in Fig. 34, and in Fig. 35 the names of parts are given. There are several methods of construction. Figure 34 is a bolted frog; some frogs are fastened together with yokes and are called yoked or

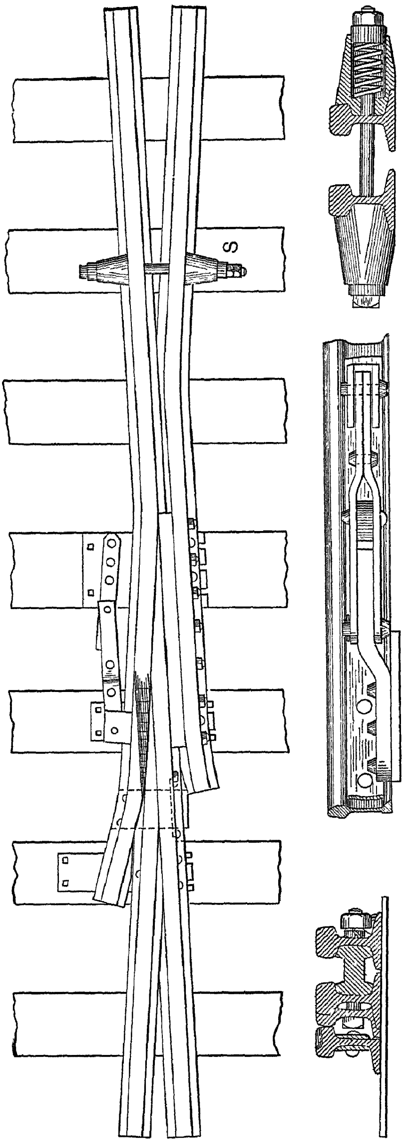


Fig. 36

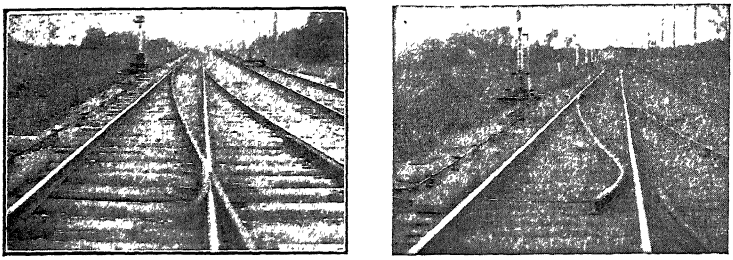
clamped frogs; others have the rails riveted to a thick steel plate. Figure 36 is a spring rail frog. The movable wing rail is held against the frog point by springs at S, thus giving continuous main track. The flange of a wheel of a car taking the siding or coming from the siding throws the spring rail over and passes through, the spring bringing the wing rail back at once after the wheel has passed.

Frogs are known by their number, which is the length from point to heel divided by the heel spread. Generally the length is taken along the middle line, making the number equal half the co-tangent of half the frog angle. Some makers use the length along the gauge side, in which case the number equals half the co-secant of half the frog angle. Expressed as equations,

$$n = \tfrac{1}{2} \cot \tfrac{1}{2} F,$$
$$n = \tfrac{1}{2} \operatorname{cosec} \tfrac{1}{2} F.$$

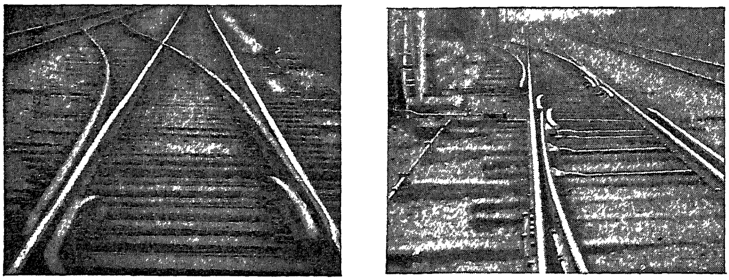
There are many patterns of frogs and switches and devices for operating them, and the student is referred to frog-makers' catalogs

for further details and patterns; he may gain much information by studying the turnout details in any depot yard of his own city or



Set for Siding Set for Main Line

Fig. 37



Set for Siding Set for Main Line

Fig. 38

town. One form of safety switch and frog — the MacPherson — is shown in Figs. 37 and 38. Its operation will be clear from the figures.

Double Turnouts. — The track arrangement for a double turnout with a stub switch shown in Figs. 39 and 40, is called a three-throw switch, and for such a switch three frogs are required. The switch rails PH and AB take three positions as indicated in the figure, according to which track is

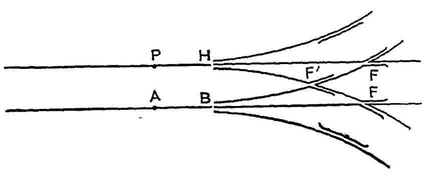


Fig. 39

to be traveled. When possible the frogs F and F are made of equal angles. The frog F′ will always be a greater angle, and is known as the crotch frog. With F and F equal, the number of F′ is 0.707 times the number of F.

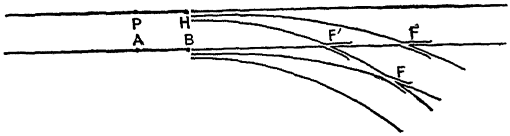


Fig. 40

Split switches cannot be made three throw from one point. They are arranged by using two complete switches, one beginning beyond the heel of the other, called a tandem arrangement, or as

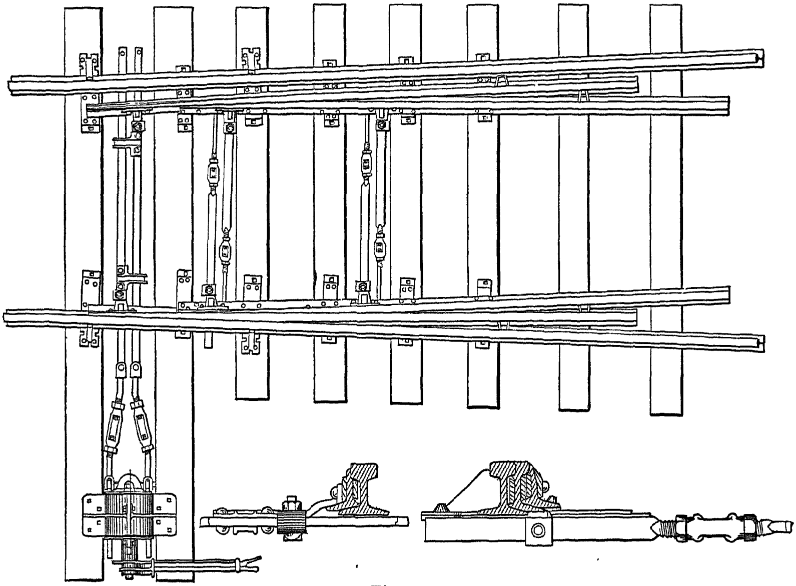


Fig. 41

shown in Fig. 41, in which one set of points is advanced about 2 feet beyond the other. In either case both switches may be operated by suitable connecting-rods from one stand.

Crossings and Slips. — When one track crosses another, the arrangement of rails is known as a crossing, and four frogs are required. If the crossing is at right angles, the frogs are all

90-degree frogs; but if the crossing is at any other angle, two frogs are acute and two are obtuse angled. The make-up of

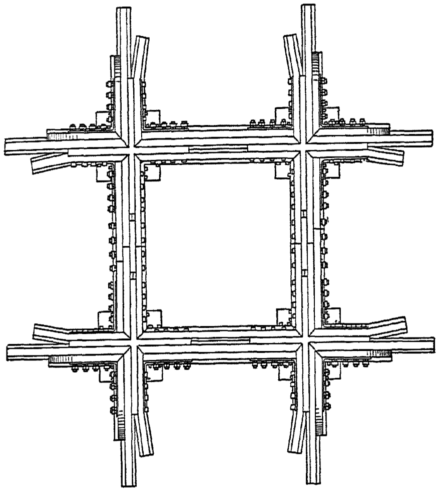
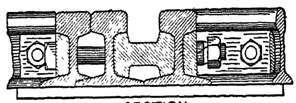
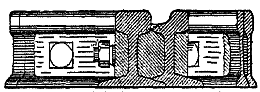
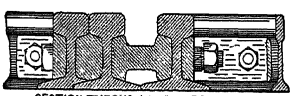


Fig. 42



the crossing is shown in Figs. 42 to 45. A 90-degree crossing is shown in Fig. 42. A crossing for electric street lines over steam lines is shown in Fig. 43, but for heavy interurban electric crossings with steam lines a standard steam railroad crossing is desirable. For the light street and steam line crossing the steam line rails are simply notched





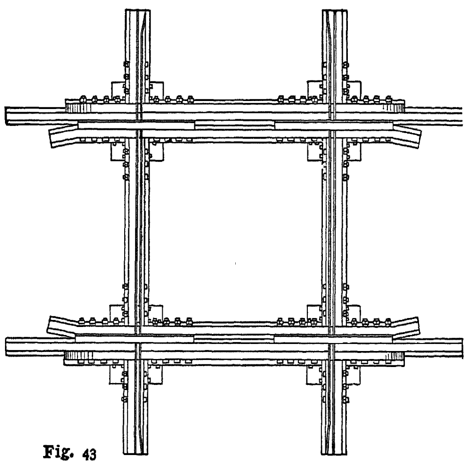


Fig. 43

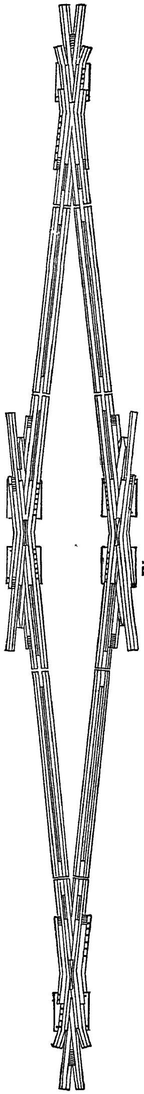


Fig. 44

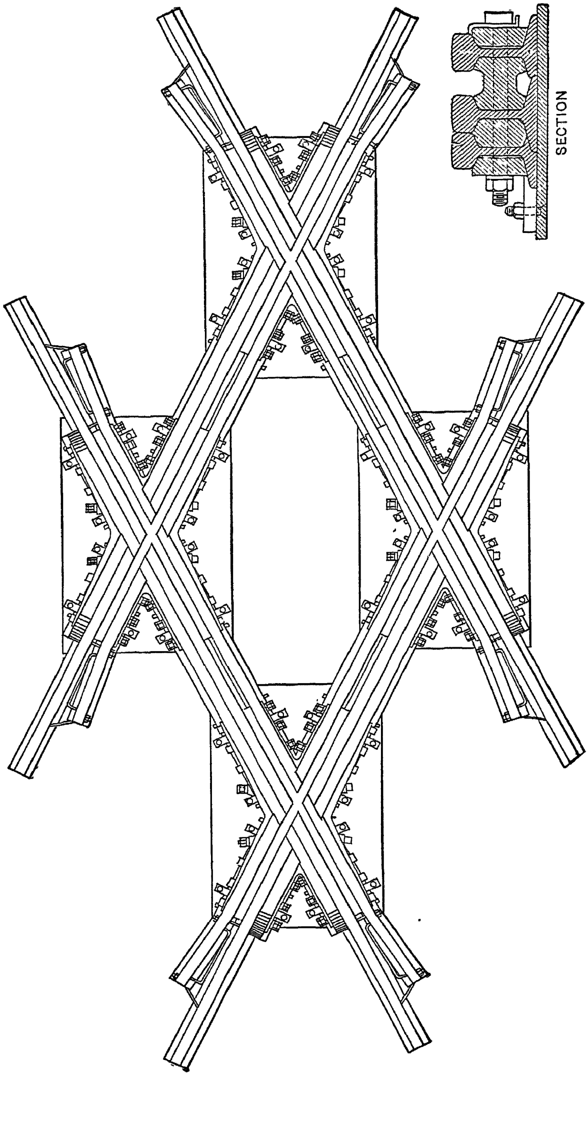


Fig. 45

for the passage of the street car wheel flanges, and no guard rail is used along the street line rails, but in the heavier crossings the guard rails are placed alongside all the rails. Figure 44 is suitable for crossings of small angles, say under 18 degrees, and Fig. 45 for crossings over 30 degrees.

When crossings are at permissible angles, slip switches may be introduced, as shown in Fig. 46. In this crossing, by a movement of the slip points that will be evident on inspection, a car from A or C may pass out at either B or D, and one from B or D

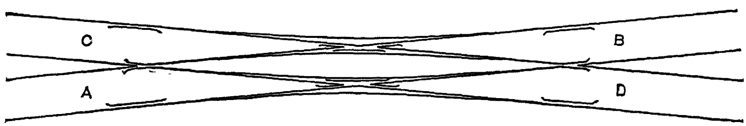


Fig. 46

may pass out at either A or C. These slip switches cannot be well introduced when the crossing is at an angle greater than about 9 degrees 30 minutes, or less than about 4 degrees. They are numbered according to the number of the crossing frogs and the above angles correspond approximately to frogs 6 and 15 respectively. Slip switches are used almost exclusively in yards, and it is sometimes considered that their number is a measure of the efficiency of the yard design, — the fewer slip switches the better the design. This is so because these switches would be used only in a ladder or lead track crossing a number of tracks, and it is considered not to be good practice to introduce such tracks. They seem sometimes to be necessary in re-designing old yards, where space is cramped and it is impracticable to secure more.

Movable Point Frog. — In connection with slip switches, movable-point crossing frogs, shown in Fig. 47, are frequently used, and such frogs are advised where the crossing angle is less than about 8 degrees, and for crossings on curves, even though the slip switch is not used. When used with the slip switches or when used for a small angle turnout frog, the movable points are thrown

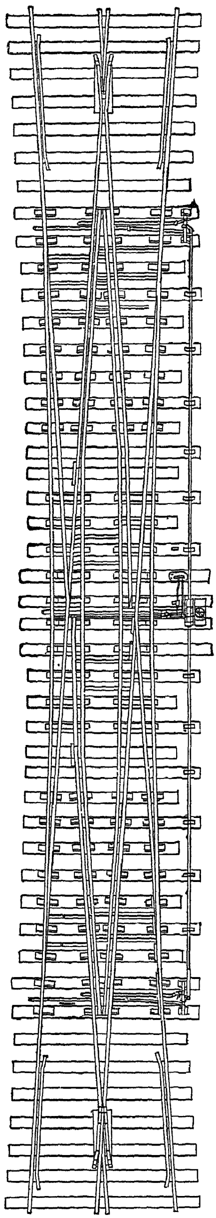


Fig. 47.

by connecting-rods and bell cranks from the same stand that controls the switch movement.

Gauntlet Tracks. — It is sometimes necessary that a double-track road shall be confined for a short distance to about the space occupied by a single track; as, for instance, when one side of a double-track bridge is temporarily disabled, or where one track is temporarily required for use in connection with improvements. Instead of introducing switches in such cases, the two tracks are run together (as indicated in Fig. 48), using two frogs, but no switches. Such an arrangement is known as a gauntlet track.

Cross-Overs.— When two parallel tracks are to be connected, this is accomplished by putting in what is called a cross-over, consisting of two turnouts and short connecting track which may be straight between frog points or curved with a reverse curve at the middle of the cross-over. The latter form is used when it is desired to make the total length shorter than would be possible with straight track between frog points.

Cross-overs between parallel main tracks should be so placed as to make trailing-point rather than facing-point switches for the main line trains, as in Fig. 49.

Laying Out. — When a turnout or crossover is to be put in, some one point in it will usually be fixed either arbitrarily or by some local condition; and when one point is fixed, the other points are determined by computation. Thus, if the position of the point of switch is known, the frog distance

determines the distance of the point of frog, and *vice versa.* With a stub switch the number of the frog and the gauge of

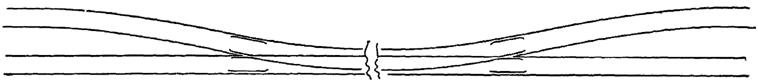


Fig. 48

the track determine the radius of the turnout curve, the frog distance, and the length of switch rail. With the split switch the length of switch rail is assumed or fixed, and that, together

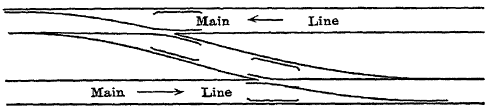


Fig. 49

with the gauge and the number of frog, determines the radius of turnout curve and the frog distance. These elements and the distance between parallel tracks determine the length of a cross-over.

The numbers 7 to 10 include the commonly used frogs. Seven is specified by the American Railway Engineering and Maintenance of Way Association as the minimum number to be used in yard design. Special track designs at stations or elsewhere require special frogs.

CHAPTER VIII

SIDE TRACKS AND YARDS

Side tracks are used at stations to permit cars to be left alongside a depot platform, or a mill or factory, and to provide for meeting or passing trains. For meeting or passing trains side tracks may be required between stations.

Yards are areas containing collections of side tracks and necessary buildings at terminal, division, or junction points. Their purposes are to provide housing for idle locomotives, repair shops for cars and locomotives, storehouses of various kinds, storage tracks for temporarily idle cars, and to facilitate the receiving and despatching of freight. The area owned and used by the railroad company at a station is known as the yard.

The proportion of side and yard tracks to main line track is about as follows: For single-track roads of light traffic 15 per cent; the proportion varies for increasing traffic up to over 100 per cent for very heavy traffic; for great trunk lines of from two to four tracks $33\frac{1}{3}$ to 50 per cent of the single-track mileage. This proportion is increasing as business increases. When for any road it becomes necessary to provide passing tracks every five miles to hold three or four trains, a new through track is desirable.

SIDE TRACKS

Small Station Sidings. — The position of side tracks at a small station will depend on the alignment, and the local topography and conditions. The station building, if there is but one, and the side track, should be so located relatively as to secure a minimum of track crossing by passengers or teams, and a clear view of the main tracks. At the same time economy of car and train movement is to be considered. If the road lies on one side of the

business center of the town or village, the station buildings should be on the village side of the main tracks.

Figure 50 shows an arrangement for a small station, safe as to track crossing and facing-point switches, but awkward for freight handling.

The arrangement shown in Fig. 51 much facilitates the handling of cars to be left at, or taken from, the station, though it introduces facing-point switches in both tracks, and necessitates the crossing of the side track by passengers, not a serious matter.

There should be separate passenger platforms for the two main tracks, that farthest from the station building reached by an overhead bridge or a subway, that there need be no crossing of a main track. American practice has not yet reached the point of abolishing track crossing at stations, but it will before many years. When the business will at all warrant it, there should be separate freight and passenger stations.

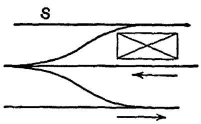


Fig. 50

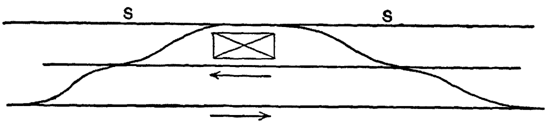


Fig. 51

The sidings shown in Figs. 50 and 51 should be a little lower than the main track to prevent cars being blown or pushed on to the main track. Where this is not feasible, stub tracks S may be placed with their outer ends buried in sand and the switches set normally for the stubs. The stub should grade down hill, outward. These precautions are advisable for any side track connecting directly with the main track, on which cars may be left for a time. Side tracks for cars to be loaded from, or unloaded into, wagons — commonly known as team tracks — should be

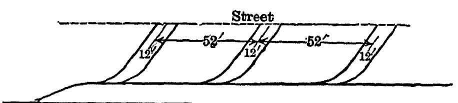


Fig. 52

so located that there need be no crossing of tracks by teams. If there are several such tracks, they should be stub tracks, the spaces between them for wagons being reached from the ends, as shown in Fig. 52. The tracks should be in pairs, each pair spaced 52 feet, center to center, and the tracks of each pair 12 feet, center to center. Ingress and egress may be provided at both ends if possible.

Passing Sidings for Single Track. — On single-track road passing sidings will be long enough to hold from two to four trains, as the business requires. On light-grade roads a train is frequently a half mile or more long. A double siding, each siding holding one train, is better than a single siding holding two trains. It is laid out as in Fig. 53.

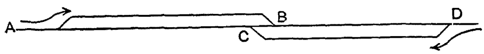


Fig. 53

If two trains meet, one takes the siding and the other the main line; if two trains meet and are to be met and passed by a third, each of the first two trains takes a siding while the third train keeps the main track. The arrangement of Fig. 53 introduces two additional switches, but permits each of the two side-tracked trains to proceed without delay, independently of each other, as soon as the road is clear, and the motion is all forward, — a very desirable condition. If any of the switches are to be operated from a tower by interlocking devices, the tower should be at the middle switches. These may be the leaving points or the entry points; if the leaving points, the tower may certainly control the leaving of the trains. If the middle switches are entering points, the trains need not stop before entering the siding, the towerman throwing the switch, and the leaving of the trains may be controlled by signals at the leaving ends, operated from the tower and interlocked with the switch which is too far away to be thrown by the towerman. If the switches are power operated, they may all be thrown from the tower.

Passing Sidings for Double-Track Roads. — For double-track roads the passing sidings may lie outside the main tracks or

between them. If between them, the main tracks must be spread and the alignment interfered with. Figure 54 shows both arrangements, the middle switches being the leaving points. If the sidings are between the main tracks, they may be connected

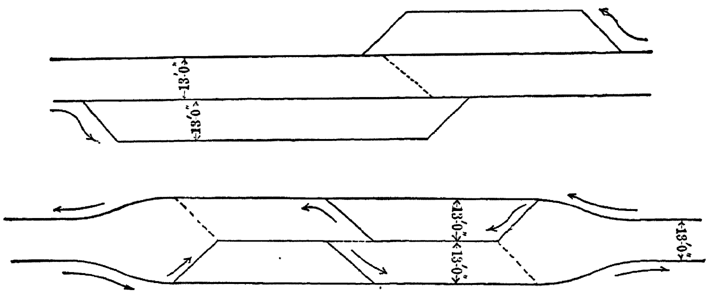


Fig. 54

and additional switches put in at the extreme ends, as shown by the dotted lines, to permit temporarily doubling the siding capacity in one direction, at the expense of that in the other.

When the sidings are outside the main tracks, the dotted crossover may be put in to permit the use of the main tracks for siding in emergencies, but it is a doubtful expedient, involving some danger. It will be noted that the emergency crossovers, which are supposed to be of infrequent use, are so placed as to give trailing point switches at the expense of backward motion of the train using them.

Relief Tracks. — On roads of heavy business these passing sidings may be long enough to permit the continual running of the side-tracked train while the fast train passes. The track is then virtually a third or fourth track, and is known as a relief track.

Siding Construction. — Compared with the main line, side tracks are apt to be of inferior construction; old, light rails and old or cull ties are used, with poor ballast and surfacing. Passing sidings, particularly relief tracks, should be of practically the same construction as the main line, the old rails and ties being used on unimportant station, mill, and gravel sidings, or spurs.

YARDS

Car Movement. — The principal point to be considered in designing a system of yard tracks is economy of movement of cars. Yard tracks are not primarily storage tracks, but sorting tracks on which trains are to be received, broken up, made up again, and despatched in the shortest possible time at the least possible expense. On New England roads the passenger-car switching is about one tenth of the whole, hence the yard tracks should be designed first for the freight traffic. This does not mean that economy in handling the passenger cars should be neglected. Freight division points and yards occur more frequently than passenger division points and yards.

A large portion of the cars handled by any railroad are received by it at terminal or junction points from other railroads. They are received in trains, or portions of trains, made up by the delivering road in the way most convenient to itself. On a road of two or more divisions, trains to go the whole of one division, but to be distributed in the second division, may be made up at the terminal without reference to the order of distribution on the next division. Varying ruling grades on different divisions may require the breaking up of through trains at division points. At a large terminal point many cars are loaded, some with through freight and some with local freight. Freight that is to go the entire length of the road or division can be most economically handled in through trains doing no switching *en route*. Local cars can be most economically handled if they are arranged in the train in station order; those to be dropped first nearest the locomotive. It is cheaper to do the necessary sorting in the forwarding yard than out on the road. Therefore, cars received or loaded at a terminal are sorted and made up into convenient trains before being forwarded. Cars thus received may be divided into classes and sub-classes, for instance:

1. Cars to go through the full length of the road or division.
2. Cars to be distributed at local stations on the division, including cars to be delivered to other lines at junction points.

3. Empty cars to be stored.
4. Cars, full or empty, needing repairs.

The first two of these classes may be divided into fast and slow trains. The fast trains will contain live stock, fresh meat, fruit, or other perishable goods. The slow trains will contain general merchandise not needing quick transportation, coal, ore, etc. Live stock is frequently shipped in trains by itself.

If road B receives a car-load of freight from road A, the freight is not transferred to a B road car, but continues to its destination on road B, which pays a rental to road A for the use of the car. Road B also becomes responsible for the return of the car in as good condition as when received, except for defects in the running gear. The Master Car Builders' rules of interchange provide in detail what parts of the car must be maintained by the operating road. It is important, therefore, that a damaged car shall not be received and operated by road B. The business of car inspecting at transfer points has thus arisen. An inspector of the receiving road, sometimes of both roads, examines every car to be received, and any found below the standard of repair required by the M. C. B. rules must be repaired before it is sent forward. If the repair is slight, the car is not unloaded; if necessary, the freight is transferred to another car.

Necessary Tracks. — It is necessary to provide tracks for the various classes of cars mentioned, and for such subclasses as may be adopted on any particular road.

The sets of tracks needed will be about as follows, a complete series of sets for each direction: —

1. Receiving tracks, a train-length long, on which incoming trains are left by their locomotives, which go by the shortest possible route to the roundhouse.

2. Classification tracks, varying in length according to the number of cars of a given class handled in, say, a half day, on which the cars of the trains left on the receiving tracks may be placed by the shunting engine. There will be as many of these tracks as there are classifications, and sometimes one set for local

and one for through cars. These may be shorter than a train length, when advance tracks are provided.

3. Local order tracks, on which the classified cars are placed in station order. These are short tracks holding from five to ten cars each.

4. Advance tracks, on which the assorted cars are placed in trains ready to be taken out by an engine coming by the shortest possible route from the roundhouse. A set of advance tracks may be arranged for fast freight only. Advance tracks must be a train-length long.

5. Repair tracks on which cars needing repairs are placed.

6. Storage tracks for empty cars temporarily idle, and for hold cars.

7. Miscellaneous tracks to coaling stations, transfer platforms, shops, depots, etc.

8. If the poling system of switching is used, there will be one or two poling tracks.

Switching Systems. — There are three systems of switching in use: tail switching or drilling, poling, and gravity switching.

1. By the first system the switch engine is attached at the rear of the train whose cars are to be sorted, pushes the train ahead and suddenly stops; one or more cars at the forward end, destined to some particular class track, have been previously uncoupled, and when the train stops continue on their way to their place. A car, or several cars together, treated in this way, is called a cut, and is ridden by a switchman who stops it at the proper place. After the first cut is sent ahead, the train is drawn back and again pushed forward to shunt a second cut; the operation is repeated till the train has all been sorted. This system, involving repeated jerking and large movement of the train backward and forward, is in decreasing favor.

2. Poling is accomplished thus: The switch engine runs on a track parallel to that on which the train to be sorted stands; the several cuts are uncoupled; the engine is stationed behind the first cut, and, through a pole or stake placed against the corner

iron of the rear car, pushes the cut ahead till it has sufficient speed to carry it to its place; the engine then returns for the second cut, and so on till the train is sorted, when another train is placed on the track and the operation repeated. Sometimes a special small poling car is attached to the engine. A switchman rides each cut to its destination. On the forward car of a cut the number of the track to which it goes is chalked or carded, and on the rear of the cut the track of the following cut. These numbers instruct the switch-tender what switches to set.

Figure 55 shows a typical poling yard design by Mr. W. L. Derr, involving the tracks already mentioned and almost no slip switches. No such yard is ever likely to be built because the local conditions, including traffic, topography, and available land, will affect the design, but the figure gives a good idea of what is required.

3. In the third system, gravity switching, the yard from receiving tracks to advance tracks is one continuous down grade, so that the cars may be run forward without any engine. An engine is sometimes needed to start the cuts, and it saves time to use an engine to bring back the men who have ridden the cuts. If such a yard is on a natural grade, trains for both directions must be received at the same end of the yard and the sorting and remaking must proceed in one direction only, thus involving backward motion through the yard for all trains running against the grade.

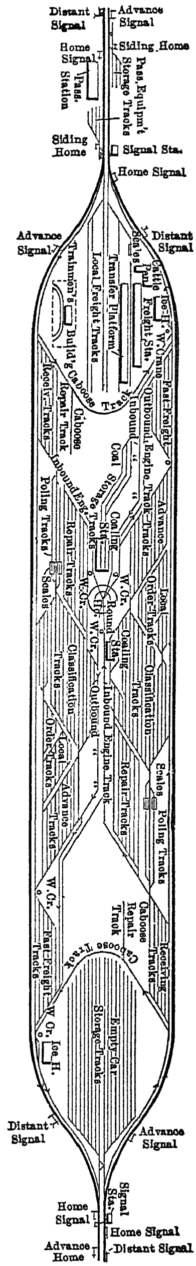


Fig. 55

Gravity yards are in rapidly increasing favor in the United States, where many so-called hump yards are being laid out. The yard is a hump yard when the grades are introduced by constructed earthwork, the topography not permitting natural grades. Such yards may be humped at both ends, providing only forward movement for trains in both directions. The receiving tracks of one set will be higher than the opposite advance tracks of the other set. Probably a better way is to put the hump in the center of the yard, the same hill serving switching movements both ways. Such a hump yard is that designed by Mr. H. M. North, C. E., for the Dupo yard of the Missouri Pacific Railroad, and shown in the figure. The absence of local order tracks and the large proportion of hold tracks are noticeable.

Yard Design. — With a single-track road all yard tracks should be on one side of the main line, to prevent crossing the main line for yard work. For the same reason it is best to spread the main tracks of a double-track road, and place all yard tracks with shops and buildings between the two main tracks.

To design a yard the engineer should know the following factors in the problem: —

The maximum length of incoming and outgoing trains in each direction, the number of freight classifications to be made for through and local cars, and the average number of cars a day of each class, prospects as to an increase in number of any class, whether or not fast freight is to be separated, the number of cars a week to be held for orders, average number of cars a day for the station where the yard is, the maximum number of crippled cars, empty cars, and passenger cars to provide for. On existing lines this information is easily secured by a conference of the departments involved, but on new lines the judgment of the engineer must be exercised.

In addition to points already mentioned, the following points should be observed in the design of a yard: Slip switches should be as few as possible, a considerable number is usually an evidence of patchwork in an old yard or insufficient study in a new yard.

Coaling station, ash pits, sand-house, and water supply should be near the roundhouse and accessible at all times.

Very long yard tracks are undesirable because of the high speed necessary to send cars the full length, and the delay caused by the long walk of the men returning from riding a cut to the end of the track. Two lay-outs showing long and short connections appear in Fig. 57 and are discussed on page 103.

Tracks for cabooses should provide for getting them quickly out of the way on arrival and make them accessible to outgoing trains without unnecessary handling.

Provision should be made to prevent fouling the main track by any ordinary switching operations. Yards of separate lines at junction points should be connected, and if some distance apart, provision should be made on the connecting tracks to hold at least one day's interchange business.

Tracks for cars to be loaded from or unloaded to wagons should be not less than 24 feet apart, center to center.* If live stock is to be handled, cattle pens should be provided at the outgoing or incoming end of the yard, as necessity may require. The inclined chutes from the ground to the floor of the car, inclined about 1 in 4, may be single for large stock or double for small stock, handled in double deck cars.

Passenger cars should not be stored in freight yards, but on tracks of their own near the passenger station.

Switches should be arranged in sets and as compactly as possible to provide for handling them from a tower by interlocking devices, if desired. They are sometimes, and about as economically, worked by hand.

The switch-light stand should be near the ground, each stand being turned by the moving rails of the switch, and furnished with two lights, showing switch set for siding or lead tracks. The track at the end of a set of parallel tracks, and from which these tracks depart, is called the lead track or ladder track. Such a lead track is sometimes laid through the middle of a set of parallel

* See p. 93 for the recommended practice of the American Railway Engineering and Maintenance of Way Association.

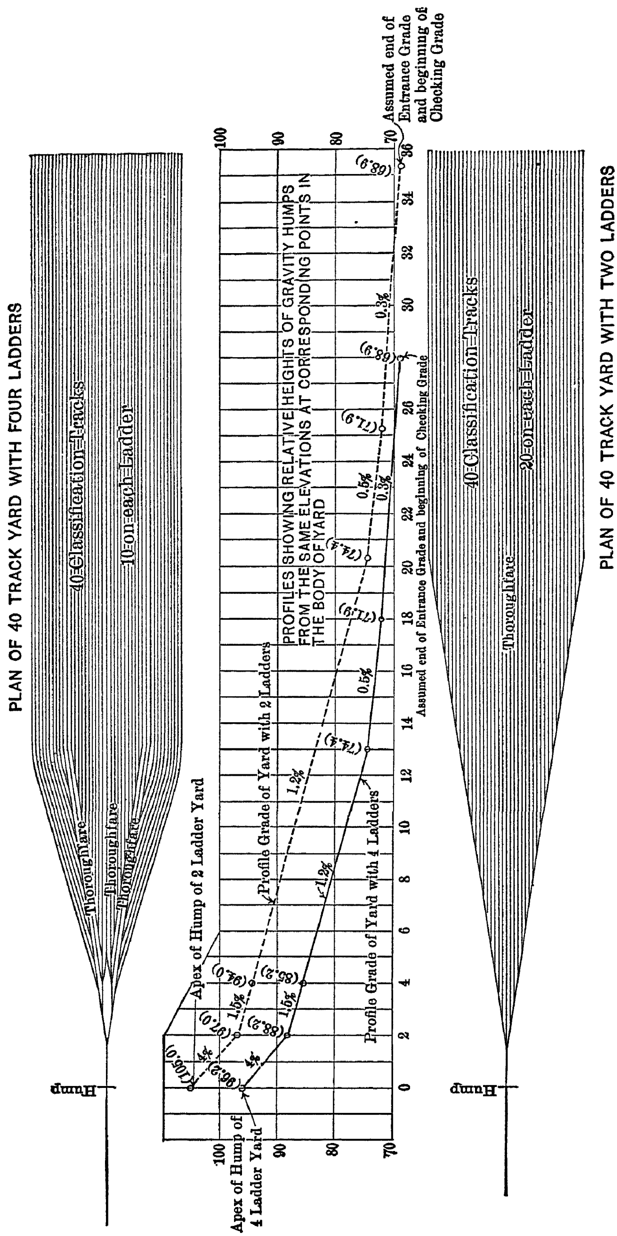

PLAN OF 40 TRACK YARD WITH FOUR LADDERS
40-Classification-Tracks
10-on-each-Ladder
Thoroughfare
Thoroughfare
Thoroughfare
Hump
PROFILES SHOWING RELATIVE HEIGHTS OF GRAVITY HUMPS FROM THE SAME ELEVATIONS AT CORRESPONDING POINTS IN THE BODY OF YARD
Apex of Hump of 2 Ladder Yard
Apex of Hump of 4 Ladder Yard
Profile Grade of Yard with 2 Ladders
Profile Grade of Yard with 4 Ladders
Assumed end of Entrance Grade and beginning of Checking Grade
Assumed end of Entrance Grade and beginning of Checking Grade
PLAN OF 40 TRACK YARD WITH TWO LADDERS
40-Classification-Tracks
20-on-each-Ladder
Thoroughfare
Hump

Fig. 57

tracks and connected with them by slip switches, but such construction should be avoided so far as possible.

Where there are many classification tracks, the entering end should be wedge-shaped to concentrate the switches, and to save wear of frogs and switches, and to shorten the leads. Not more than eight or ten body tracks should lead off from one lead or ladder track. Some of the advantages of the small number of body tracks for each lead track are shown in Fig. 57.*

Automatic scales should be provided on the track connecting receiving and classification tracks. On these scales cars are weighed as they pass over. Dead tracks should be provided close to the scale track for passing cars not to be weighed, that the scales need be used no more than necessary. The dead tracks may be supported on posts set in the scale pit.

At important stations where much bulky and heavy freight is to be handled between cars and wagons or trucks, one or more cranes should be provided convenient to one or more of the team tracks.

Telegraphic, telephonic, or bell-signal communication should be established between the train despatcher's office and roundhouse, yard offices, and block stations. A telephone, supplemented by bell signals operated under a code, is perhaps the best means of communication.

Yards to be used at night should be well lighted. Electric lights are best, but must be carefully placed where they will be of most service, very high from the ground, and not near any signal; they are placed high to reduce the shadows. Electric lights make the best switch lights.

Main-track yard switches should be operated from a central station and interlocked with main-track signals.

Water cranes should be located at the engine-house, at points where switch engines work, at coal pockets if far from the engine-house, and at the outgoing ends of the yard. A main with hydrants about 200 feet apart should be located along the receiving

* From "The Theory of Design of Railway Freight Terminals," a valuable paper before the Western Society of Engineers, by H. M. North, C. E.

tracks for the use of car inspectors, and there should be water at cattle pens. There should be fire hydrants near important buildings and near storage tracks.

Air hose and an air brake testing plant should be provided for departure or advance tracks.

Yard Buildings. — Ordinary yard buildings will consist of roundhouse, ice-house, yard office, car inspectors' stations, signal stations, sand-house, repair shop, and a building for the use of the trainmen waiting for trains. Bins holding links and pins may be placed at convenient points. The foundations of buildings near tracks must be carefully looked after and made firm. Standard clocks should be fastened to masonry piers reaching firm foundations and entirely detached from floors of buildings. Icing stations are needed at all division terminals; they should be placed near the outgoing end of the fast-freight tracks on a separate track, accessible alike to incoming and outgoing trains, and so arranged that the incoming road engine may take cars to be iced directly to the icing station where the outgoing train may take them on. The utmost care and thoroughness in under draining, surface draining, and ballasting a yard will be high economy.

Passenger Terminals should have a series of cross-overs outside the station to permit movement from one track to another; there should be more tracks than are absolutely necessary, to allow for special trains, to get an incoming train out of the way of the passage of its engine to the engine-house, and to permit making up trains at the station when necessary. When there is a considerable suburban service, provision must be made, as on elevated and other rapid transit roads, to shift the locomotive from one end of the train to the other. On rapid-transit roads it is necessary to do this quickly. If the tracks come into the terminal straight, the trains must stop far enough from the ends to permit the placing and operating of cross-overs that the engine may get back to the other end of the train. Where it is possible to introduce it, the loop terminal is the most satisfactory plan, as it allows the most rapid movement of trains with least movement of engines. The engine is not uncoupled from the train; no switching is neces-

sary. This plan has been adopted in the South Boston Terminal, and Grand Central Station in New York, the stations being two stories, through trains entering and leaving above the loop terminal of the local and suburban trains.

Suburban trains are usually run at more frequent intervals at certain hours of the day, and storage tracks must be provided

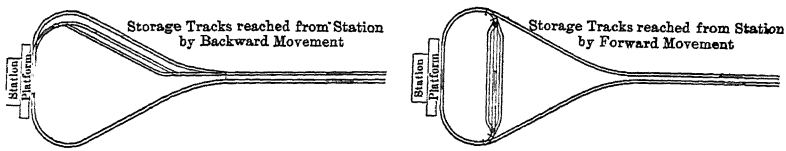


Fig. 58

for temporarily idle trains. With the loop system these can sometimes be placed in the loop, the best method, requiring no backward movement, being shown in Fig. 58.

Terminology. — A set of tracks in a large yard is sometimes called a yard, — as, classification yard, advance yard, storage yard, etc. It has been advised that the aggregation of such yards be called a cluster. The author suggests that the term yard most properly belongs to the whole area occupied by yard tracks, buildings, etc., at a way station or terminal, and that therefore the whole area should still, as always heretofore, be called the yard, and the separate groups of tracks called the clusters, — if that is the best word to use; and it is as correctly used for a cluster of tracks as for a cluster of yards. This arrangement will interfere less with general terminology than to change the whole yard to cluster. A word of one syllable would be better, and the use of plot is suggested. Thus, there would be the terminal, division or station yards, and the classification, advance, or storage plots in those yards. But perhaps classification, advance, or storage tracks will answer as well.

The American Railway Engineering and Maintenance of Way Association recognizes yard as applying to the whole system of tracks, and also to the several groups themselves, — as, the yard, departure or forwarding yard, team delivery yard, etc.

Water Terminals. — At important coast terminals, provision must be made for trans-shipment to and from vessels, and at such points as New York City, actually reached by the freight tracks of but two railroad systems, while the opposite Jersey shore is reached by many more, provision must be made for trans-

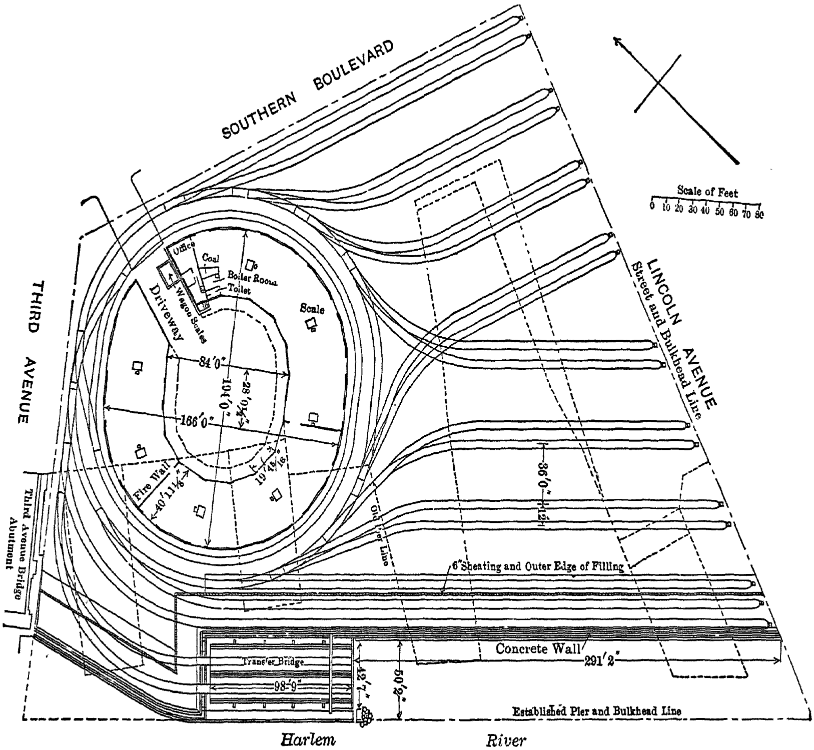


Fig. 58 *a*

fer across the separating body of water. The method of trans-shipment depends on the commodity. Light merchandise is usually unloaded from or loaded into cars run out on a pier inside or alongside a freight shed in which the merchandise is stored for loading to cars or vessels. Grain is handled through elevators directly from boats to cars, or *vice versa*, or it is handled

through floating elevators or lighters which may load to the vessel in the stream. On the Pacific coast grain is handled in sacks instead of loose as in the Eastern States.

Freight for New York received on the Jersey coast is transferred across the river on barges or floats, the cars being run on to and off the floats over transfer bridges whose inclination may be varied to suit the state of the tide. Small yards are necessary on the New York side. Their shape and size will depend on the available land and amount of business to be done. They will usually consist of a set of team tracks arranged in pairs, with a scale and a crane at proper points and a freight shed for temporary storage of freight received in less than car-load lots. One design for such a terminal is shown in Fig. 58*a*.

CHAPTER IX

ELEVATION OF THE OUTER RAIL

Reason for Canting the Track on Curves. — When a train leaving a tangent enters a flat curve, it is forced to take the curved path by the induced pressure of the outer rail on the flanges of the outer wheels. This deviating force is communicated to the car body through the truck and center pin. Because of the inertia of the car this force produces an overturning moment measured by the product of the force and the distance from the rail to the center of gravity of the car. The greater the speed of the train, or the sharper the curve, the greater the lateral force and overturning moment. That the car may be in no danger of leaving the rails or destroying the track, a flat curve must be taken at very slow speed. If the speed is to be considerable, the necessary deviating force must be obtained by canting the track.

Canting Formulas. — The conditions that exist are shown in Fig. 59. An induced centrifugal force may be said to act horizontally at the center of gravity of the car. Gravity measured by the weight of the car may be said to act vertically through the same point. It is required that the resultant of these two forces shall be normal to the transverse surface of the track. Under this condition there can be no lateral pressure due to the centrifugal force. The figure shows that this condition is secured when the tangent of the angle of inclination equals centrifugal force divided by weight. This is the mechanical value of the tangent.

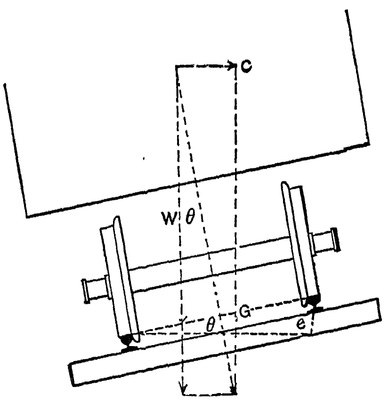


Fig. 59

The cross distance between inside of rail heads is the gauge of the track, but the distance between bearing points of wheels is a little less than the distance between rail centers, which, though a variable quantity, may be taken as 4.9 feet for standard gauge. The distance between bearing points of the trackman's gauge is practically the distance between rail centers, therefore, this distance will be used in deriving formulas. The difference in level of the outer and inner rails is called the "elevation of the outer rail." The figure shows that the tangent of the angle of elevation equals the elevation divided by the horizontal projection of the distance between bearing points. This may be called the linear value of the tangent. Equating the mechanical and linear values for the tangent of the elevation angle, and solving for the elevation, gives

$$e = \frac{4.9}{\sqrt{1 + 223.64 \dfrac{R^2}{S^4}}} * \qquad (1)$$

in which R is the radius of the curve in feet, and S is the speed in miles per hour.

It is usually assumed that the horizontal projection of the distance between bearing points is that distance itself, that is, the cosine and radius for small angles are equal. This assumption simplifies the formula to the form commonly used: —

$$e = \frac{0.3273 S^2}{R}. \qquad (2)$$

The constant multiplier 0.3273 is not that commonly used, but is believed to be more correct than the usual constant 0.3147, by

* Centrifugal force $C = \frac{mv^2}{R} = \frac{Wv^2}{gR}$ in which v is in feet per second, R is the radius of the curve in feet, and g is the acceleration of gravity = 32.2 feet, approximately.

$$\text{Tangent } \Theta = \frac{C}{W} = \frac{v^2}{gR} = \frac{e}{\sqrt{G^2 - e^2}}.$$

Changing v into miles per hour S, substituting 32.2 for g, *and* 4.9 *for* G, *and* solving for e, gives Equation (1).

reason of the use of 4.9 feet for gauge instead of 4.705 feet. The ordinary formula is sometimes given in terms of the degree of curve instead of the radius, the latter being assumed to be $5730 \div D$. Using the constants 0.3273 and 0.3147 respectively, and reducing to inches, there results $e = 0.000685\, S^2D$ inches and $e = 0.00066\, S^2D$ inches, which, put into a simple rule, gives: —

RULE: The difference of level in inches of the two rails of a curved track of standard gauge is from two thirds to seven tenths of one one-thousandth of the square of the speed of passing trains multiplied by the degree of the curve.

The difference in elevation resulting from these formulas amounts to more than ¼ inch for high speeds. This is an appreciable difference. Track inclined according to formula (1) will secure smooth passage of cars when the speed equals S. While the formula is awkward, the trackman always works from a table which should be computed on a rigid basis.

Connecting with Tangent. — The practice in canting the track varies. It will be evident that, since the centrifugal force is instantly generated to its full amount at the beginning of the curve, the track should have its full theoretic inclination at this point and should be level across an infinitesimal distance away on the tangent, — a manifest impossibility. Where no spirals are used, it is common to begin the inclination on the tangent a distance from the curve found by allowing from 25 to 50 feet for each inch of difference in rail levels, the full inclination being attained at the beginning of the curve. When spirals are used, since they vary in degree directly with their length, the inclination begins at the point of spiral and increases uniformly to the main curve, where it is the full theoretic amount. The inclination by this method is everywhere what it should be. The proper length of spiral curve is usually determined by considering at what rate the inclination of track may be obtained with comfort to passengers. If the inclination is secured by lowering the inner rail and raising the outer rail, keeping the center line at grade, the full inclination may be secured in less distance than if the more common practice

is followed; namely, keeping the inner rail at grade and raising the outer rail through the full difference in level. Talbot thinks the rate of securing the inclination should be stated on a time, rather than a distance, basis; that is, it should be *n* feet per unit of time rather than *n* feet per unit of distance, and that therefore the distance rate and consequent length of spiral curve will vary with the speed. This is doubtless true, but the sensations are so slight that it is probably unwise to consider more than two rates, — one for low-speed trains, say, 20 miles an hour, and one for high speeds, say, 50 miles an hour. For the former a rate of 1 in 300 is ample, and for the latter double that will certainly be sufficient. Thus, a curve requiring 6 inches inclination for a given slow speed would require spirals 150 feet long; while a curve having the same elevation for a high speed, would require spirals 300 feet long. The Track Committee of the American Railway Engineering and Maintenance of Way Association advises a rate of 1 inch in 60 feet for a general rule. The author believes 1 inch in 50 feet sufficient. Less than this is ample for good line maintenance.

Speed to be Assumed. — The formula indicates that the inclination varies with the square of the speed. Not all trains on any road travel at the same speed. The practice varies as to the speed used for the formula. On some roads an average speed is assumed, and all curves inclined for this speed; on others the average of the passenger train speeds is assumed and all curves inclined for this speed; again, the fastest speed is assumed; on some roads a different speed is assumed for ascending and descending grades, feasible only on multiple track roads; on some roads a variation is made as between curves on ordinary grades, say, under 1.0 per cent, and curves on steep grades; and on a few roads care is taken to note the position of each curve in the track, the speed at which it is to be taken by the fast trains using the track, and to prepare inclination tables for trackmen accordingly. This last-named practice is undoubtedly productive of the best results. A curve at a stopping point needs little or no elevation, a curve on an ascending grade will be taken slower

than on a descending grade of the same rate. Near summits of long grades the speed will be less than in or near the low points; through yards, even though not stopping points, the speed will be less than on the open road, as it will on certain long, high bridges; and a road pretty much all curves will be operated at less speed than one nearly all tangent. Each curve should be numbered and studied by itself, and suitable tables prepared for trackmen's use.

Maximum Inclination. — It is probably best to incline the track for the ordinary speed of the fastest train using it, up to a maximum of 8 or 9 inches for tracks used only for passenger service, and to about 6 inches for freight tracks or tracks used for both freight and passenger service. No particular damage is likely to occur from taking a curve at slightly greater speed than that for which it is inclined, but the excess speed does not exceed 5 to 7 miles per hour with safety. A slow-moving freight train on an excessively inclined track is likely to hug the inner rail too hard, and overturning of top-heavy loads on the inside of the curve is not unknown, and excessive wear of the inner rail is common on curves always taken at a low speed by heavy trains.

Outer Rail *vs.* Both Rails. — European practice raises the outer rail and lowers the inner rail, keeping the center line at grade. American practice generally follows this rule for new construction, but in surfacing existing track keeps the inner rail at grade and raises the outer rail through the whole required difference. This practice doubtless gave rise to the term "elevation of the outer rail." The European practice is advised for American roads. The American practice introduces a short grade at the beginning of the curve. This grade is unpleasant when taken at high passenger speed, and may introduce a limiting effect when taken by a slow-moving freight train on a ruling grade. Thus, if the full elevation is 6 inches, the center line rises 3 inches; and if this is accomplished in 150 feet, a grade of $0.16\frac{2}{3}$ per cent 150 feet long is introduced on a level or added to any existing grade. This addition might easily stall a heavily loaded locomotive just able to ascend the nominal grade.

Resulting Pressure on Outer Rail. — Although the inclination of the track entirely counteracts the centrifugal force due to curvilinear motion, the car trucks must be turned on the center pin through whatever central angle the entire curve subtends, and the car body must be turned about its central vertical axis through the same angle. This is accomplished directly by the induced pressure of the outer rail against the flange of the front outer wheel of each truck. This pressure causes the car and truck to rotate, the wheels slipping on the rails. There is then always a pressure against the outer rail, but it does not vary with speed or radius of curve (with slight exceptions hereafter noted). This slipping on the rails is what causes what is known as curve resistance, and it will be more fully treated under that head.

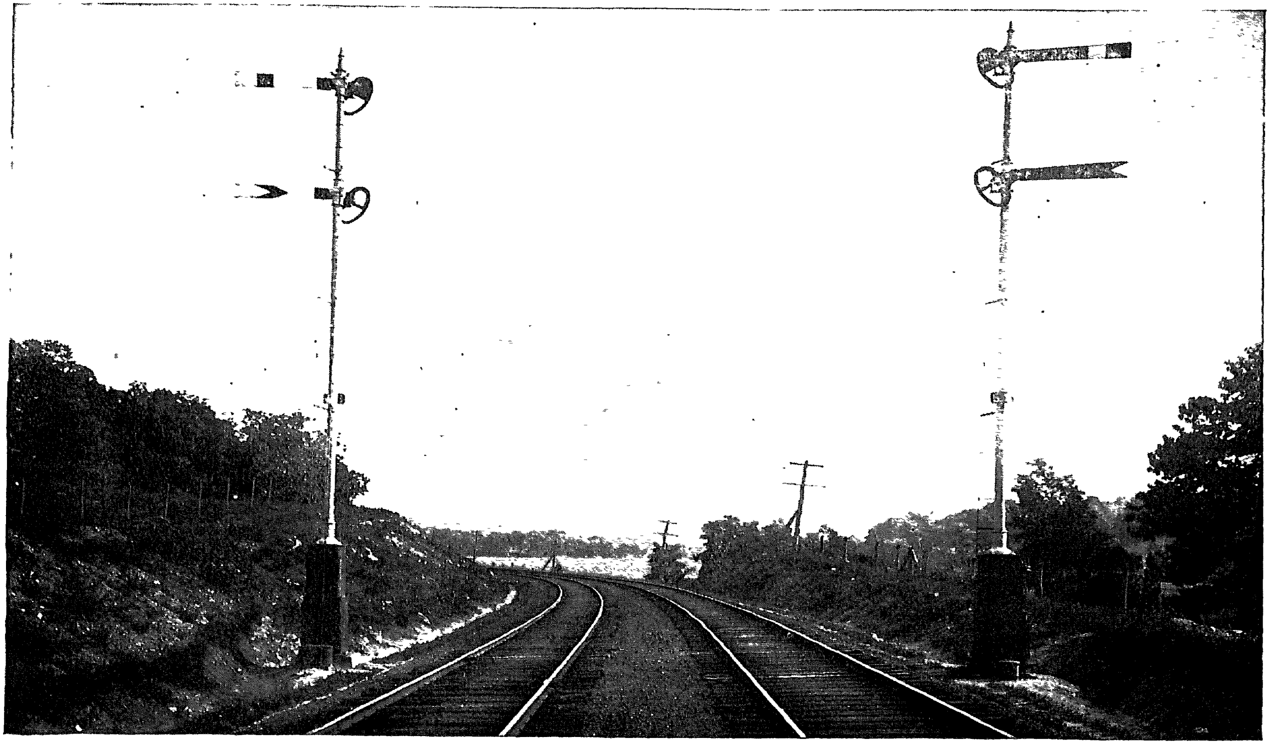
There is also an overturning moment applied to the inner rail due to the friction of the wheels slid across the top of the rail. The resulting pressure against the outer rail is that necessary to slide all of the wheels that slide; but the pressure necessary to slide the front wheel itself is balanced by the friction of sliding which is deducted when determining the pressure that reaches the spikes or that acts to form an overturning moment. There is a momentary greater pressure while the locomotive and each car is entering the curve due to impact. This pressure is very largely overcome by spiraling the curve. It is this pressure that always puts the end of an unspiraled curve out of line.

CHAPTER X

SIGNALING

Defined. — As a term in railroading, signaling means informing the engineman of a train whether he is to proceed or stop. Sometimes some additional information is given, as, which of several tracks he is to take, but the definition given is essentially correct. Signaling is so intimately connected with switch movements that these, where controlled by a signalman in a tower, are included in the general term signaling.

How Accomplished. — The information is given in daytime by the position of a blade or arm pivoted near one end on a vertical post, and at night by colored lights. The blade or arm signal is called a semaphore. Besides the semaphore, disk signals are somewhat used; these consist of a disk made to turn either its edge or broadside toward the engineman, or made to appear and disappear behind the glass window of an enclosing case. Their disadvantage is that they are essentially a color system. When a semaphore is used, if the arm stands at right angles to the post, the indication is "danger," "stop "; if the arm is dropped some 60 degrees, it means "all right," "go ahead." Sometimes three positions are assumed: right angles — stop; inclined — go ahead under control expecting to be stopped; vertical — go ahead. Opinions vary as to the desirability of three positions, and the general English practice is to give two orders only. With disk signals the edge, or absence of the disk means "track clear — go ahead," while the broadside or appearance of the disk means "danger — stop." The color scheme for lights at night varies on different roads. The English practice is red for "danger — stop," and green for "clear — go ahead." In America the prevailing practice is red for stop; green for caution — go ahead under control; and white for clear — go ahead.



Normal Danger Electro-Gas Automatic Signals on the New York Central and Hudson River R.R.

The semaphore system is moved by power or by hand; if by power, it is either compressed air acting in a cylinder on a piston which is connected to the signal by a rod, or compressed gas, or electricity acting generally through a motor. The air is furnished by a compressor conveniently located, and is carried in pipes to the signals to be operated; its action is controlled either by an electric current or by another supply of compressed air at lower pressure actuating the valves of the cylinder. The electric current is controlled by a signalman in a tower or cabin built alongside the track, or works automatically through the rails, the circuit being broken by the entrance of a train into the section of track where the current for a particular signal is flowing. The auxiliary air supply for actuating the signal cylinder valves is controlled by a signalman in a tower. Some disk signals are operated by clockwork controlled by an electromagnet.

When signals are moved by hand, a signalman in a tower pulls a lever which is connected with this signal by a rod (gas pipe) or two wires, by which the signal is operated. The signalman in the tower is informed by telegraph, telephone, or electric bell signals what signals he is to give various trains.

Two General Divisions. — Signaling is divided into two general classes: 1. Block signaling. 2. Interlocking and signaling. Block signaling is the division of a railroad line into spaces of various lengths, called blocks, and the placing and operating of signals at the end of each block to tell the engineman of an approaching train whether or not the block ahead of him is clear, and hence whether or not he may proceed. Block signaling keeps trains separated by space intervals, which are much safer than time intervals.

By interlocking and signaling is meant a system of interlocked switches and signals, or signals alone, at grade crossings, sidings, cross-overs, and in terminal or other large yards, so arranged that before the switches of one route may be set and signaled clear for a moving train, all other routes or switches or signals that could be so set as to permit another train to foul the route to be cleared, must be set to make this impossible.

Signaling Economical. — It will appear that the chief object of all signaling is safety, but it is also true that by preventing accidents that cause delay and money loss, and by giving advance information to enginemen so that when the line is clear — as is the usual case — they may keep up high speed, even approaching grade crossings, and by concentrating a number of switch levers at one point, signaling and interlocking greatly expedite the safe movement of trains, and increase the traffic capacity of the road, and hence expenditure for signals is not only the price of safety but is real economy, even for lines of comparatively thin traffic.

Block Signaling. — Block signaling may be applied to either single or double track, but for single track it is not so simple as for double track. There are three principal methods of operating block signals: 1. Telegraphic. 2. Controlled manual. 3. Automatic.

Let a double track be first supposed. By the telegraphic method of operating block signals, the signalman in the tower at the rear or entering end of a block informs the towerman at the forward or leaving end when a train enters the block, and the forward towerman informs the rear man when the train has passed out of the block. The rear towerman will not give the clear signal to an approaching train until the forward man has told him the last train through is out of the block.

The signals are what are called "mechanical," that is, worked through levers by hand, and the normal position is danger, the signal being cleared by the signalman for each approaching train, provided he learns the block is clear. The signal is supposed to be held clear till the train has passed it and into the block, when it is at once restored to danger. The information from one tower to another is given by telegraphic code or a bell code, or both.

In the controlled manual method the signals are worked by hand, as in the telegraphic method, but the signal levers are electrically interlocked, so that the forward operator must unlock the levers in the rear tower before the rear towerman can move the signals to the clear position. The locking mechanism is worked by an electric circuit. On the approach of a train toward any

block, the towerman asks the towerman ahead to "clear" him; if the block is clear, the forward towerman pushes a button or plunger and unlocks the rear operator's levers, after which that operator can give the clear signal. The advance towerman having once unlocked the levers of the tower at the entering end cannot again do so until his own signal has been cleared and again set at danger, which will not occur until the train he has admitted to the block shall have passed his own tower. The method is safer than the telegraphic, in that it requires a positive action on the part of two men to clear a signal, which having been cleared and moved again to danger cannot be again cleared till the block it controls is clear. The normal position of the signals is danger.

In the automatic method an electric battery is placed near the forward end of a block and the current is run through the rail and through a relay, which, so long as the current flows, completes a circuit from a second battery that operates the signal mechanism. The device is so arranged that an accident to the apparatus would send the signals to danger, hence the automatic system must always be a permissive system; that is, the engineman finding a signal at "stop," does not know whether it is so because of a train in the block ahead or because of derangement of the mechanism; he therefore stops a prescribed time, and then goes ahead with caution. In the non-automatic system a signalman is always present to tell the engineman whether or not he may go ahead at speed, under control, or not at all; nevertheless, the automatic system is in growing favor.

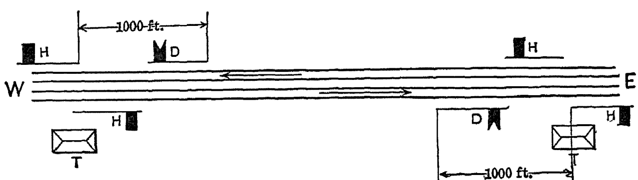
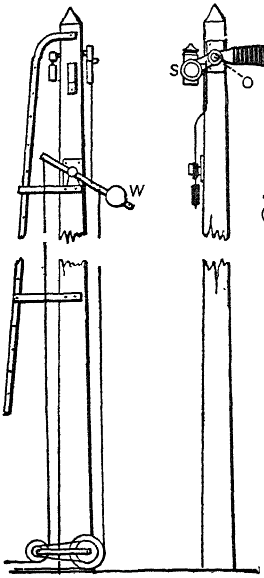


Fig. 60

General Forms of Signals. — Figure 60 shows the relation of a semaphore signal and the track it governs. The blade is always

to the right of an approaching train; if to the left, no attention is paid to it because it governs movement in the opposite direction. H is the home signal, D the distant signal, and T the tower.

Figure 61 is a standard home semaphore, so called because it is located at the beginning of the block it governs near the signal cabin or tower; while Fig. 62 is a distant signal, so called because it is located at some distance from the home signal toward



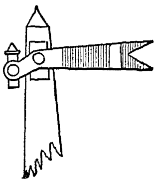


Fig. 62

Fig. 61

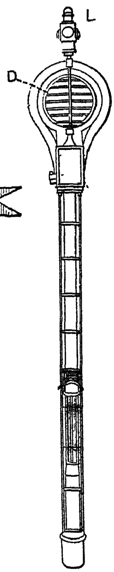


Fig. 63

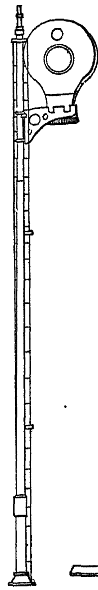


Fig. 64

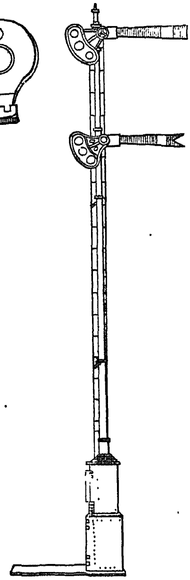


Fig. 65

an approaching train. The distance is not so great as to prevent operation from the same cabin, say, 1500 to 2000 feet. The distant signal is always in the same position as the corresponding home signal, and is used to tell the engineman in advance what information he may expect to find at the home signal, so that if it is "clear" he need not reduce speed for a possible stop; and if it is "stop," he may approach the home signal under control. B is the blade pivoted to the post at O; S is a frame carrying a red glass, and is called the spectacle. A lamp is on the bracket

behind the spectacle, and when the signal is in the stop position shows its light through the red glass of the spectacle; when the blade is pulled down to "clear" the spectacle rises, disclosing the white light of the lamp. When green is used for the clear signal, or when permission to go ahead under control is given by the signal, the spectacle is double or triple; if double, one glass is red, the other green; and if triple, a third opening is vacant for white, as in Fig. 65. W is a counterweight which keeps the signal at stop except when the signalman pulls and holds the lever. The signal shown is worked by wires. The one difference between the home signal and distant signal is the notch in the end of the distance blade, though they are sometimes painted differently. The post is from 25 to 30 feet high. In yards, for slow movements, short posts with small arms and spectacles, called dwarf signals, are used. Usually where several parallel tracks are to be signaled, the signals are placed on an overhead bridge spanning the tracks, each signal over its own track.

Figures 63 to 65 are forms of automatic signals. Figure 63 is the clockwork signal of the Union Switch and Signal Co. The disk D is turned by the weight of the clock within the hollow post; broadside means stop, edge means clear, go ahead; the lamp L shows the proper light by turning with the disk. These signals are not now being made, though some of them are in service.

Figure 64 is the Hall banjo signal. A red disk appears at the larger opening for stop and disappears for clear, the proper light appearing at the small opening above. It is electrically operated, the connection being within the hollow post and banjo top. The disk in Fig. 63 is exposed to the weather, but is protected in the signal shown in Fig. 64. Figure 65 is a three-position automatic semaphore.

For two parallel tracks on which trains travel in the same direction, as on four-track roads, the signals may be arranged on a bracket post, as in Fig. 66, and when the distant signal of one block is placed at the beginning of the preceding block, both blades may be on one post, as in Figs. 67 and 68. In single-track signaling the blades for opposite moving trains may be, but are not

commonly, on one post, projecting in opposite directions, — always to the right of the approaching train they govern.

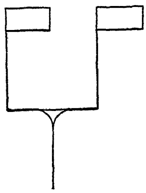


Fig. 66

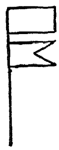


Fig. 67

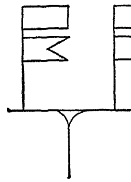


Fig. 68

Operation of Automatic Block System. — The general method of operation of the automatic block system may be explained with the aid of Fig. 69. WE is a block of an eastbound track.

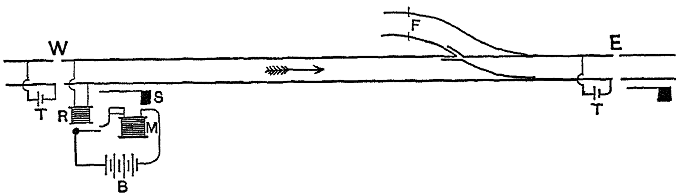


Fig. 69

The arrangement would be duplicated for a westbound track, hence one description will answer for both. T is the track battery, one or two gravity cells, located at the forward end of the block, the two poles being connected through the two rails and a relay R at the rear or entering end of the block. While the current flows the relay is energized and its armature made to close a circuit including the signal battery B and electromagnet M. A pair of wheels, or any conductor, joining the two rails within the block, short circuits the current, deënergizes the relay, and breaks the signal battery circuit. The electromagnet M, which is attached to the signal post, either directly or indirectly controls the movement of the signal. If the signal is moved by clockwork, it starts this clockwork, which runs for a quarter turn of the signal (disk type) and stops; if by compressed air or liquid gas, the

electromagnet opens the valve, admitting the supply to the cylinder containing the piston which moves the signal; if by an electric motor, the electromagnet makes the necessary circuit closure for the motor. Clockwork signals, though still in use, are no longer made; the tendency is to the power semaphore, because a position signal as distinguished from a color signal, is recognized as the most easily visible under all conditions of weather.

If one or more side tracks or cross-overs leave the main track within the block, they may be included in the rail circuit as far as the fouling point F, so that a pair of wheels between F and the point of switch would short circuit the current just as if on the main track; or a circuit breaker may be connected with the switch, whereby if the switch is set for the siding the circuit is broken and the signal S will go to danger.

The foregoing description introduces no distant signals, and in early automatic blocking there were none. Overlaps, distant signals, and three-position signals are now used. By overlap is meant that a short portion of track east of E — say, 2000 feet — is also connected with relay R and controls signal S, which will not go to clear till the train has passed beyond the overlap. The common method of arranging distant signals is to put the distant signal of one block on the same post with the home signal of the preceding block, the distant signal being below the home signal.

Another device is the three-position signal, doing away with the second blade. The single blade in a horizontal position signifies stop; in an inclined position — stop at the next block; vertical — all clear in the immediate and following blocks.

In the example given above the signals have been supposed to be normally at clear, to go to danger when a train is in the block governed or from any derangement of the electric currents. Perhaps this is the more usual type, but the electric system may be so arranged that the signals are normally at danger, as in all manual systems, a signal being cleared by the entrance of a train in the preceding block (provided, however, that the governed block is clear), and returned to danger by the entrance of the train into the governed block and held there, in spite of a train

in the preceding block, so long as the governed block is occupied or its circuit broken by an accident.

Single-Track Block Signaling. — Except at terminals where there are several tracks, single-track roads may generally be divided into larger blocks than double-track roads, because of their usually fewer trains, though for an equal number of trains the blocks should be shorter. The block may be the whole distance between stations, when the simple telegraphic system, handled without any regular addition to the station force, or the train staff system, will be the most economical. The controlled manual, modified for single track, may be used, but some form of automatic signals will be found most satisfactory for roads of much traffic. Frequently not the whole line, but only dangerous — because crooked — or busy portions are signaled. The train staff may be used for short sections, as important bridge crossings, where absolute, as distinguished from permissive, signaling must prevail.

The Train Staff. — The train staff is a peculiar device consisting of two holders, one at each end of a block, containing a number of short cylindrical bars of wood or metal, and so connected with electric locks that after one bar — called a staff — has been removed from one holder, no more bars can be removed from either holder till the one removed has been returned to one or the other of the holders. The number in each holder is supposed to be sufficient to provide for any possible temporary inequality in train movement in the two directions. The engineman entering a block is given a staff which he gives up at the end of the block. No engineman has a right to be in a block without a staff, unless by permission given, which is sometimes necessary to provide for unusually heavy traffic in one direction. Permission is given by withdrawing a special permission staff which is a key to a box on the machine containing a number of tablets. If several freight trains are to follow one another in close succession, a tablet may be given each engineman, to the last, who must be given all the remaining tablets and the permission staff, for neither machine or holder can be unlocked until all the tablets and per-

mission staff are in one or the other of the two holders. To guard against sidings being left open between two staff stations, the staff is made a key to the switches, and the locks so arranged that after the switch is unlocked and opened the key cannot be withdrawn until the switch has been closed and locked. The holders of two adjoining blocks are of different pattern to prevent the mistake of returning a staff to the wrong machine or holder, of which there are always two in each signal cabin. Signals are also arranged and interlocked with the staff machines. For high-speed movement mechanical devices are used on the locomotive and at the station for catching and delivering the staffs. In operation, the concurrent action of the men at both ends of the block is required to release a staff at either end from its holder, a system of bell signals between the stations being arranged for communication. The system may be made absolute in its action by interlocked derailing switches, and is then perhaps the safest of all block systems; the engineman knows as certainly as it is possible to know that if he can get a staff and get into a block, no other train can get into the same block while he is there. The system does away entirely with the movement of trains by train order.

Automatic Signals, Single Track. — When automatic signaling is used, signals on opposite sides of the track and opposite ends of the block give the same indication. If both are normally clear, a train entering one end puts them both at danger, the two signals being connected by a pole line. In order that two trains may not enter at the same instant at opposite ends of the block, a distant signal may be used at one end, or an overlap introduced. The home signal may be set a short distance in the block so that the engineman may see it go to danger as he enters. Blocks are usually from 1 to 4 miles long, but in automatic blocking should be not more than $1\frac{1}{2}$ miles.*

In the New York subway express trains are run through blocks as short as 450 feet, and never more than 1000 feet long. The

* For further details of block signalling consult signal companies' catalogs and "The Block System" by B. B. Adams (*Railroad Gazette*).

automatic signals and overlaps permit a train to proceed only when the preceding train is at least in the second block ahead. Should a motorman undertake to run by a signal set at stop, an automatic track device will engage a valve on his car, releasing the air of the air brakes, and the resistance of the brakes stopping the car will run the current to the motors so high that the automatic circuit breaker will act and cut out the current, thus, so far as possible, seemingly avoiding dependence on the human element for safety. The subway is double tracked.

Interlocking a Single-Track Crossing. — The figure shows a single-track grade crossing of two roads. D indicates distant

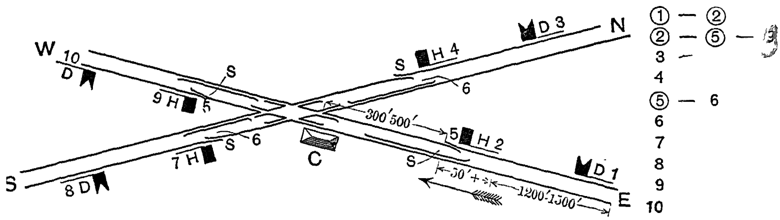


Fig. 70

signal; H, home signal; S, derailing switch; the numbers are the numbers of the levers actuating the signals and switches, these levers being concentrated in a single frame in the cabin or tower C. The levers are so interlocked in the frame that if the derails of one line of track, say EW, are closed and signals 2 and 1 set at clear, the derail levers of line NS are locked open, and all other signals are locked at danger, the signalman in the tower being unable to change them until the cleared signals have been restored to danger and the derails of EW opened. The normal position of all signals in this case being danger, the levers are said to be normal when holding the signals in their normal position, and reversed when holding them clear. So the derails when open are normal, when closed, reversed. Let a train come from E: the signalman, first — reverses lever 5, closing both derails on EW, and automatically locking 6 normal; second — reverses 2, clearing the signal and automatically locking 9 normal

and 5 reversed; third — reverses 1, clearing the distant signal and locking 2 reversed. The train may then proceed, sure of no conflict with a train from either direction on NS or an opposing train on EW, if the engineman of such a train obeys his signals. The levers must be returned to normal in reversed order, — returning 1, unlocks 2, which being returned locks 1 normal and unlocks 5 and 9, and 5 being put normal unlocks 6, and the system is ready to be set for a train in any direction. The arrangement of the numbers at the side is called the locking chart, the figures in a circle indicating the reversal of the corresponding lever; thus the second line reads, "2 reversed locks 5 reversed, 9 normal." Only the locking for the train movement illustrated is given. The student may complete the chart.

Cross-Over. — A cross-over between parallel main tracks may be considered. If the frame of the machine in the cabin is in sets of four levers, there will be one spare lever; and since both switches may be thrown by one lever, let the spare lever be No. 4.

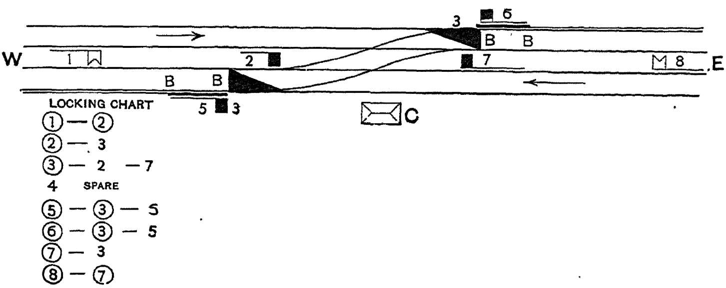


Fig. 71

The signals 5 and 6 always governing slow motion into the cross-over are dwarf signals, the others high signals. It is assumed that there is never high speed westward on the eastbound track, nor eastward on the westbound track, hence no distant signals for 5 and 6 are required. The black triangles indicate by their slope the normal position of the switch, which in this case is set for the main line. Let it be supposed that a train coming from the west is to be stopped and moved over the cross-over to the west-

bound track. The switches are found set for the main track and all signals at danger. First, signal 2 is cleared, then signal 1, and the train passes to the east of the switch; signals 1 and 2 are then put normal, switch 3 reversed, signal 6 cleared, and the train passes through the cross-over. If the movement has been for the purpose of allowing a faster eastbound train to pass the train under consideration, that train remains on the westbound track protected by signals 7 and 8; signal 6 is returned to danger, switch 3 set normal, and signals 2 and 1 reversed to permit the fast train to pass, after which signals 1 and 2 are set normal, switch 3 is reversed, signal 5 reversed, and the first train allowed to pass on to the eastbound track, after which signal 5 is set normal, switch 3 normal, and the track is ready for another train in any direction.

Detector Bar. — One important adjunct of interlocking is a long, heavy, steel bar, BB, set close against the outside of the rail in a position relative to the switch shown in Fig. 71. This bar is so connected with the lever that it is raised a little ahead of the movement of the switch, and unless it can be so raised the switch cannot be thrown. Its purpose is to prevent the signalman from throwing a switch under the wheels of a passing train, which will always have a pair of wheels over the detector bar, preventing it from rising.

Manual Machines. — There are two types of manual interlocking machines, that in which the locking bars are arranged in a horizontal plane, and that in which these bars are arranged in a vertical plane. The Saxby & Farmer machine is the representative of the first type, shown in Fig. 72*, and the General Railway Signal Company's style A machine is representative of the second type, shown in Fig. 73. The levers will be evident; the latches attached to each control the locking bars, so that when a lever is to be reversed its latch must first be lifted, and this locks such levers as are to be locked by a reversal of the lever in question before that lever can be reversed. Thus, in the last diagram, Fig. 71, lifting the latch of lever 5 locks levers 3 and 6 before lever 5 is reversed. This is known as preliminary

* From Union Switch and Signal Company's catalog.

locking. Machines of the Saxby & Farmer type require more floor space than the vertical type machines, and are suitable for

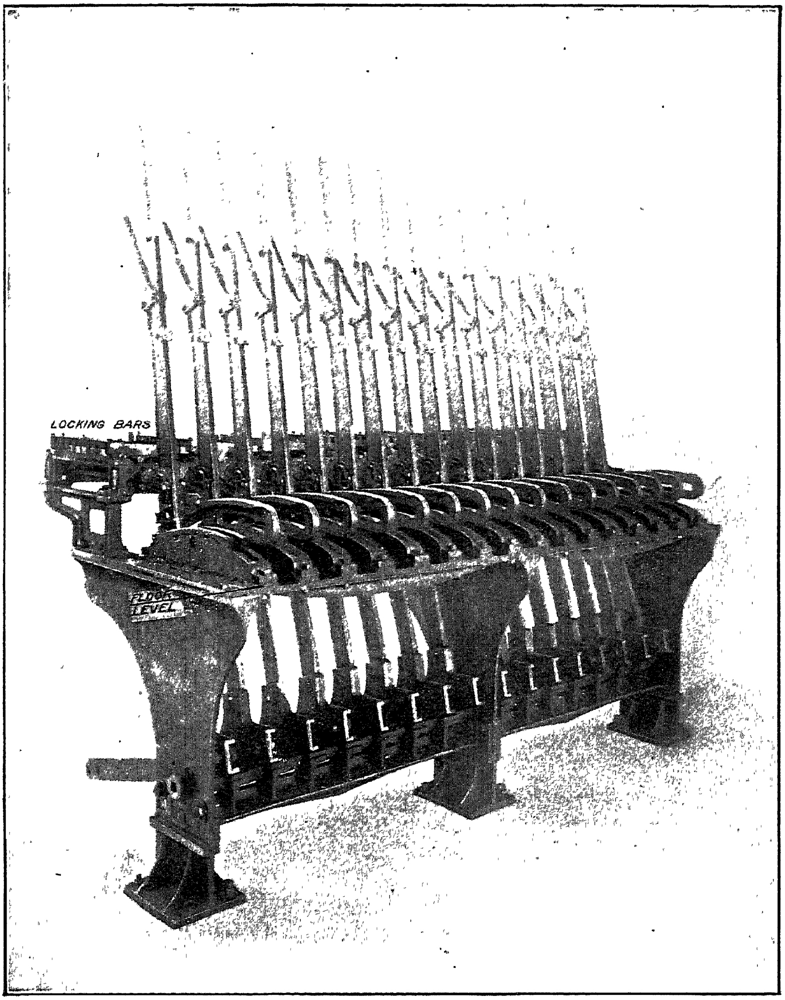


Fig. 72. Saxby and Farmer 16 Lever Machine

a ground floor or a low cabin on a bridge. The vertical type, requiring less floor space, are particularly suitable for a tall cabin.

Power Interlocking Machines. — When a large yard is to be interlocked, manual interlocking becomes too slow and requires a large number of men. Power interlocking has been devised to overcome these difficulties. Power machines are of three types, electro-pneumatic, pneumatic or "all air," and "all electric." With the first, compressed air at about 70 pounds is used to move the switches and signals by means of cylinders and pistons attached

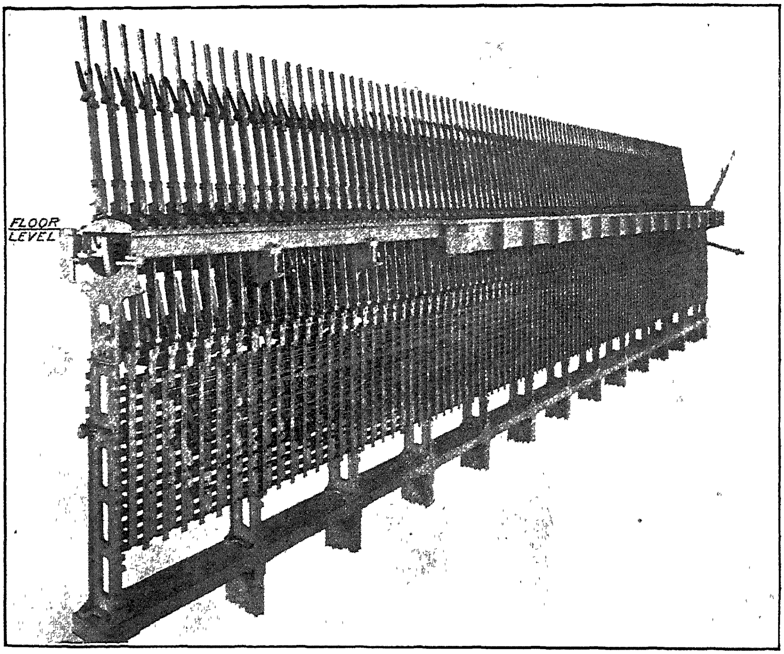


Fig. 73. Lever Vertical Locking Machine

to the sleepers or signal posts, the valves for these cylinders being controlled by electromagnets actuated by a current of electricity controlled by the interlocked levers — electric switches — in the signal cabin. In the second type, air at a pressure of about 15 pounds is used to move switches and signals, and the control of the valve is through a second supply of compressed air at about half the pressure of the main supply, and which is con-

trolled by the interlocked levers — slide valves — in the signal cabin.

In the third type, electric motors of about 1 horse-power move the switches, and motors of about $\frac{1}{6}$ horse-power the signals, the current for these being controlled again by the interlocked levers in the cabin.

In all of these power machines the levers — so called — are small, and require very little strength for their operation; the manual levers very frequently, particularly for distant signals, require about all the strength of an average man.

The all air system is not so quick as the all electric, but is sufficiently quick for all ordinary work where the distance is not too great.

In the power machines the locking is preliminary, as in the manual machines, and the complete movement of the switch lever is impossible until the switch has been thrown, so that if the reversal of the lever is begun and the switch does not move, the reversal cannot be completed, and the operator knows something is wrong.

PART II

THE LOCOMOTIVE AND ITS WORK

THIS part of the book will discuss the hauling capacity of the locomotive; the resistances it overcomes in hauling trains on straight and level track, grades, and curves; the cost of operation and the variation in cost due to a variation in number and weight of trains and in rise and fall, distance, and curvature; all of those matters sometimes classed under "Economics of Location." Reference books to be read in connection with Part II, are Wellington's "Economic Theory of Railway Location," Goss's "Locomotive Performance," Henderson's "Locomotive Operation," The Pennsylvania Railroad's "Locomotive Tests and Exhibits," Forney's "Catechism of the Locomotive" and the statistical reports of the Interstate Commerce Commission.

CHAPTER XI

THE LOCOMOTIVE

General Statement. — The locomotive consists essentially of an internally fired boiler and a pair of simple, or one or two pairs of compound, steam cylinders, mounted on a frame which rests on a truck and, through a system of equalizing levers like a platform scale, on the driving-wheel axles. The driving wheels correspond to the fly wheel of a stationary engine, and the track corresponds to the belt. The belt being fixed, and the engine free to move, the result of the effort of the cylinders to turn the drive wheels is motion of the engine along the track.

Tractive Effort of Adhesion. — There would be no such motion if there were no friction between the wheels and the rails; the wheels would spin around on the track. This spinning often occurs when the engine is too heavily loaded, when the track is slippery, or when the engineman opens the throttle too quickly at starting. It is because of this friction that the locomotive is able to move and pull a load, and the ultimate tractive force that it can exert equals the weight on the drivers multiplied by the coefficient of friction between wheel and rail. That is, this is the resistance it offers to sliding along the track; and if the cylinder power is equal to this, the engine will move against a force approximating this resistance. A greater resisting force applied to it will cause the drivers to slip if the cylinder power is sufficient.

Three Locomotive Elements. — In the locomotive there are three elements, any one of which may determine its capacity to do work. 1. The boiler or steam making element. 2. The cylinder or steam using element. 3. The weight on the drivers and coefficient of friction, or what may be called the adhesion element. If the boiler capacity be small, the quantity of steam generated at the required pressure in a unit of time will be small;

the steam must therefore be used slowly and the result will be slow speed or very light loads requiring little steam for tractive effort. If the cylinder capacity be small, the engine will be unable to haul the load indicated by the tractive force of adhesion, while using steam at full pressure. The tractive force of adhesion is limited by the weight that it is safe to concentrate on the drivers and move over the track.

Cylinder Tractive Effort. — Work is force multiplied by the distance through which it acts. If a wagon is pulled 10 feet with a force of 5 pounds, 50 foot-pounds of work is done. The work that can be done by a cylinder at one double stroke — that is, one revolution of the drivers — is given by multiplying the pressure on the piston by twice its stroke. Since there are two cylinders in a simple locomotive, the work that can be done at a single revolution of the drivers is twice the work done by one cylinder.

> Work in foot-pounds of both cylinders during one revolution of drivers = unit pressure in cylinder (pounds per square inch) × area of piston (square inches) × 4 single strokes (feet).

This work advances the locomotive on the track a length equal to the circumference of the drivers against the resistance to motion of the train and locomotive, which resistance must be equaled by the tractive effort of the locomotive.

> Work done in foot-pounds in moving a train a distance equal to the circumference of the drivers = tractive effort of the locomotive (pounds) × circumference of drivers (feet).

There is a slight loss in overcoming the friction of the moving parts of the engine variously estimated and shown by test to be from 5 to 10 per cent of the indicated power of the cylinders. Neglecting this loss, the work done in the cylinders equals that done in moving the train. This being so, if the effective pressure in the cylinders, the area and stroke of the piston, and the diameter

of the driver be known, the cylinder tractive effort is found as follows: —

Let P be the mean effective steam pressure per square inch in the cylinder for the whole stroke, A the area of the piston, L the length of stroke, D the diameter of the drive wheels, and T_c the tractive force in pounds. Then,

$$PA \times 4\,L = \pi D T_c$$

whence
$$T_c = \frac{PA \times 4\,L}{\pi D}.$$

If d be the diameter of the piston,

$$T_c = \frac{Pd^2 L}{D}.$$

From this equation it is evident that with a given cylinder and pressure the tractive force will be greater as the diameter of the drive wheels is smaller. With a given piston speed the speed of the train will be greater as the diameter of drivers is greater. For these reasons it is usual to build locomotives for heavy freight service with small drivers, and those for fast passenger service with large drivers.

Variation of Tractive Effort with Speed. — So far as the equation for T_c is concerned, it would appear that with given driving wheels the cylinder tractive effort should be the same at all piston speeds, since speed does not enter the equation. This is not so, because at high speeds the mean effective pressure in the cylinders cannot be maintained at so high a percentage of the boiler pressure as at slow speeds. At a piston speed of 135 feet per minute, corresponding to about 5 miles per hour with stroke of 26 inches and small drivers of 54 inches diameter, approximately 90* per cent of the boiler pressure can be realized in the cylinders. At a piston speed of 500 feet per minute, giving

* Not over 80 per cent allowed by the Pennsylvania Railroad experts at the St. Louis locomotive tests.

with the same stroke and 60-inch drivers a speed about 20 miles per hour, only 65 per cent of the boiler pressure can be realized; while with a piston speed of 1100 to 1200 feet per minute, giving with 78-inch drivers about 60 miles per hour, rather less than 30 per cent of the boiler pressure can be realized as mean effective pressure in the cylinders.

Every steam boiler and engine combination properly proportioned is designed to develop some definite horse-power. A horse-power is a peculiar compound unit equivalent to a force of 33,000 pounds acting through space at the rate of 1 foot per minute, or 550 foot-pounds of work per second. If such work is performed for an hour, there is produced what is called a horse-power hour. Within certain practical limits the power of a steam plant may be used to overcome great resistance at slow speed or little resistance at high speed. So long as the work, force times distance, done in a unit of time remains constant, the factors force and distance may be varied at will, within limits.

A locomotive is such a steam boiler and engine combination. If a given locomotive be designed to develop $I.H.P.$ horse-power, the work it will do in a minute is 33,000 $I.H.P.$ foot-pounds; in one hour it will do $60 \times 33{,}000$ $I.H.P.$ foot-pounds, or

$$\frac{60 \times 33{,}000}{5280} I.H.P. \text{ mile-pounds.}$$

If this power is expended in drawing a train requiring a tractive effort of T pounds at a speed of S miles per hour, the work done on the train in one hour is TS mile-pounds, and this must equal the work developed in the cylinders of the locomotive, or

$$TS = \frac{60 \times 33{,}000}{5280} I.H.P.$$

So long as the product TS — that is, the work done in a unit of time — remains constant, the factors T and S may be varied at will, that is, a heavy train may be hauled at slow speed, or a light

train at high speed, the tractive effort that the locomotive can exert at any speed being given by

$$T = \frac{60 \times 33{,}000}{5280S} I.H.P.$$

or

$$T = \frac{375\ I.H.P.}{S}. \tag{1}$$

This is a general formula applicable to all motors whose power capacities are known.

Since a small portion of the cylinder power of the locomotive is lost in internal friction, it is probable that the net available tractive effort of any locomotive is more nearly given by

$$T = \frac{340\ I.H.P.}{S}. \tag{2}$$

These equations are true only within limits. If S is so small that T exceeds either the ultimate cylinder tractive effort or the tractive effort of adhesion, the equations fail, since T cannot be greater than either of these quantities, and whichever is the smaller fixes the ultimate tractive effort of the locomotive. Again, there is a practical limit to the speed of the piston travel, and at very much higher speeds than the locomotive is designed for, the steam will not flow rapidly enough through the steam passages and valves to realize the full power of the locomotive. The formula is good within the working range of any particular locomotive. The formula last written will give sufficiently close results for most problems coming to the engineer of permanent way.*

Horse-Power. — In describing locomotives it is usual to mention total weight, weight on drivers, heating surface, grate area, diameter of drivers, area and stroke of piston, boiler pressure carried, and a varying number of other features depending on the

* The student should plot the curve of both formulas on axes of T and S.

completeness of the description, but the horse-power of the locomotive is never mentioned, as it is in describing a stationary steam plant.

The horse-power produced by any steam engine during a given period equals the work done in the cylinders per minute divided by 33,000. The work done equals the product of the mean effective pressure per square inch on the piston, the area of the piston in square inches, the length of the stroke in feet, and the number of single strokes in one minute; the first two factors giving total pressure and the last two distance through which that pressure acts.

Expressed as a formula easy to remember

$$I.H.P = \frac{PLAN}{33{,}000}.$$

I.H.P. means indicated horse-power, *P* the mean effective pressure determined by an instrument known as an indicator, *L* the length of the stroke, *A* the area of the piston, and *N* the number of strokes in one minute.

In a simple locomotive there are two cylinders, the piston of each making a double stroke for each revolution of the drivers, hence the *N* of the formula is four times the revolutions per minute.

At slow speed of 5 or 6 miles an hour, the cylinder may receive steam throughout practically the full stroke of the piston, and the mean effective pressure in the cylinders may approximate 90 per cent of the boiler pressure. The other 10 per cent is taken up by certain small frictional losses in the steam passages, unavoidable back pressure, etc.

In computing ultimate cylinder tractive effort the mean effective pressure is usually assumed at 85 per cent of the boiler pressure.*

Quantity of Steam. — But no practicable boiler could keep up a supply of steam at high pressure if a cylinder full were used

*Eighty per cent assumed by the Pennsylvania Railroad experts at the St. Louis locomotive tests.

at each stroke at high speed. The valves that admit steam to the cylinders are so controlled by the engine driver through the valve gear that the entrance of steam to the cylinder may be cut off at any portion of the stroke, the remainder of the stroke being made under the steam's expansive force, which decreases as the volume increases, thus making the mean effective pressure during the whole stroke much less than the initial pressure, which at low speed may approximate the boiler pressure and at high speed may be 90 per cent of that pressure. A given quantity of steam at a given pressure contains potentially a definite quantity of work, a more or less definite portion of which may be realized in the cylinder of a steam engine, and if the point of cut-off is so varied with the speed that a constant quantity of steam shall be used in a unit of time, the output of power will be approximately constant. This condition obtains only approximately in practice.

It has been determined * that the modern types of simple locomotives require about 28 pounds of steam per horse-power hour.

Heating Surface. — The quantity of water evaporated into steam in a boiler depends on the kind of fuel used, the rate at which it is burned, and the area of the metal having fire or the heated gases of the fire on one side and water on the other. The area of boiler metal exposed to the fire or heated gases and having water on the other side is called the heating surface. There is some difference in the evaporation from the different portions of the heating surface, the sides of the furnace, the tubes, etc.; but as locomotive boilers are usually designed, it is a fair estimate of usual working with good fuel to assume 12 pounds of water evaporated per hour for each square foot of heating surface.†

Boiler Tractive Effort. — If 28 pounds of steam per hour are required to produce one continuous horse-power in the cylinders, and 1 square foot of heating surface will evaporate 12 pounds of

* Professor W. F. M. Goss, in a paper before the New England Railroad Club, practically confirmed by the Pennsylvania Railroad locomotive tests at St. Louis in 1904. See page 140.

† Professor Goss in a paper before the New England Railroad Club. See also page 140.

water per hour, then each square foot of heating surface will produce $\frac{12}{28}$ or 0.43 of 1 cylinder horse-power. The horse-power of a locomotive boiler may therefore be given by 0.43 × square feet of heating surface. What may be called the boiler tractive effort may be determined by substituting $0.43H$, H being square feet of heating surface, for I.H.P. in equations (1) and (2), page 135, giving

$$T_b = \frac{375 \times 0.43\,H}{S} = 161\frac{H}{S}\cdot \qquad \text{Gross.}$$

$$T_b = \frac{340 \times 0.43\,H}{S} = 146\frac{H}{S}\cdot \qquad \text{Net.}$$

Three Equations for Tractive Effort. — The three expressions derived in the foregoing paragraphs for the tractive effort of a locomotive are

$$\text{Tractive effort of adhesion, } T_a = fW. \qquad (1)$$

$$\text{Boiler tractive effort, } \quad T_b = 161\,\frac{H}{S}\text{ Gross, } 146\,\frac{H}{S}\text{ Net.} \qquad (2)$$

$$\text{Cylinder tractive effort, } T_c = \frac{Pd^2L}{D}. \qquad (3)$$

The tractive effort of adhesion does not vary with speed but only with conditions of the rail and driving wheels affecting the coefficient, f, of friction between them. Under any assumed conditions this effort is constant. Under ordinary summer conditions $f = \frac{1}{4}$; in winter it may be assumed as $\frac{1}{5}$; with sand and a dry rail $\frac{1}{3}$ has been realized, but if the drivers begin to slip, f drops to probably less than $\frac{1}{10}$. T_a is given in pounds when W, the weight on the drivers, is stated in pounds.

The modern tendency to heavy trains has demanded heavy locomotives. The weight on a single driver is limited by the

strength of the supporting track and structures. While much depends on the pattern of the rail and the character of its support, it is customary to say that each 10 pounds per yard of steel rail section in good American track will safely support 3000 pounds of concentrated load. By this rule 70-pound rails should carry single driver loads of not exceeding 21,000 pounds; while 100-pound rails will permit driver loads of 30,000 pounds. Modern locomotives generally range between 21,000 and 24,500 pounds per driver; a good many have less weights and a few have greater weights. Balanced compound locomotives are frequently built with heavy driver weights because the balancing of the engine reduces the blow given by the counterweights of simple unbalanced engines.

Boiler tractive effort is given in pounds, the heating surface H being given in square feet, and the speed S in miles per hour.

Cylinder tractive effort is given in pounds, when the mean effective pressure P is in pounds, the diameter of the piston d, the length of stroke L, and the diameter of the drivers D, are all in inches. L and D may be in feet or other like units, but are usually given in inches. Neither the boiler tractive effort nor the cylinder tractive effort can ever exceed the tractive effort of adhesion, though the boiler and cylinders may both be capable at low speed of developing a tractive effort in excess of that of adhesion. The results of attempting such development would be to slip the drivers.

St. Louis Tests. — The Pennsylvania Railroad Company established a locomotive testing plant at the Louisiana Purchase Exposition in St. Louis in 1904 and made a series of tests on several types of locomotives. The design of the plant followed that of Professor Goss of Purdue University. The results of the tests are published in a volume by the Railroad Company. This volume, and a more recent publication by Professor Goss,* should be consulted, for the most reliable and complete data known concerning American locomotive performance and the effect of variation of details of design.

* "Locomotive Performance."

The following general conclusions are taken by permission from the Pennsylvania Company's publication, and are subject to the limitations applying to any summary, namely, "Any attempt to summarize must necessarily pass over important facts and must in some cases involve statements which, because of their incompleteness, are not entirely free from objection." Not all the conclusions are given; only those that seem pertinent to this discussion.

BOILER PERFORMANCE

At maximum power, a majority of the boilers tested, delivered 12 or more pounds of steam per square foot of heating surface per hour; two delivered more than 14 pounds, and one, the second in point of size, delivered 16.3 pounds. These values expressed in terms of boiler horse-power per square foot of heating surface are 0.34, 0.40, and 0.47 respectively.

The evaporative efficiency is generally maximum when the power delivered is least. Under conditions of maximum efficiency, most of the boilers tested evaporated between 10 and 12 pounds of water per pound of dry coal. The efficiency falls as the rate of evaporation increases. When the power developed is greatest, its value commonly lies between limits of 6 and 8 pounds of water per pound of dry coal.

THE ENGINE

The indicated horse-power of the modern simple freight locomotive tested may be as great as 1000 or 1100; that of a modern compound passenger locomotive may exceed 1600 horse-power.

The maximum indicated horse-power per square foot of grate surface lies, for the freight locomotives, between the limits of 31.2 and 21.1; for the passenger locomotives, between the limits of 33.5 and 28.1.

The steam consumption per indicated horse-power hour necessarily depends upon the conditions of speed and cut-off. For the simple freight locomotives tested, the average minimum is 23.7. The consumption when developing maximum power is 23.8, and when under those conditions which proved to be the least efficient, 29.0.

The compound locomotives tested, using saturated steam, consumed from 18.6 to 27 pounds of steam per indicated horse-power hour. Aided by a superheater, the minimum consumption is reduced to 16.6 pounds of superheated steam per hour.

In general, the steam consumption of simple locomotives decreases with increase of speed, while that of the compound locomotive increases. From this statement it appears that the relative advantages to be derived from the use of the compound diminish as the speed is increased.

Tests under a partially opened throttle show that when the degree of throttling is slight, the effect is not appreciable. When the degree of throttling is more pronounced, the performance is less satisfactory than when carrying the same load with a full throttle and a shorter cut-off.

THE LOCOMOTIVE AS A WHOLE

The percentage of the cylinder power which appears as a stress in the draw-bar, diminishes with increase of speed. At 40 revolutions per minute, the maximum is 94 and the minimum 77; at 280 revolutions per minute, the maximum is 87 and the minimum 62.

The coal consumption per dynamometer horse-power hour, for the simple freight locomotives tested, is at low speeds not less than 3.5 pounds nor more than 4.5 pounds, the value varying with running conditions. At the highest speeds covered by the tests, the coal consumption for the simple locomotives increased to more than 5 pounds.

The coal consumption per dynamometer horse-power hour, for the compound freight locomotives tested, is, for low speeds, between 2.0 and 3.7. Results at higher speeds were obtained only from a two-cylinder compound, the efficiency of which under all conditions is shown to be very high. The coal consumption per dynamometer horse-power hour for this locomotive at the higher speeds increases from 3.2 to 3.6 pounds.

The coal consumption per dynamometer horse-power hour, for the four compound passenger locomotives tested, varies from 2.2 to more than 5 pounds per hour, depending upon the running conditions. In the case of all these locomotives, the consumption increases rapidly as the speed is increased.

A comparison of the performance of the compound freight locomotives with that of the simple freight locomotives is very favorable to the compounds. For a given amount of power at the draw-bar, the poorest compound shows a saving in coal over the best simple which will average above 10 per cent; while the best compound shows a saving over the poorest simple which is not far from 40 per cent. It should be remembered, however, that the conditions of the tests, which provide for the continuous operation of the locomotives at constant speed and load throughout the period covered by the observations, are all favorable to the compound.

Compound Locomotives. — Compound locomotives have either two or four cylinders. A very few have been built with three cylinders, but none in America. The two-cylinder locomotives have on one side a small high-pressure cylinder in which the steam is partly expanded, and from which it passes to a larger low-pressure cylinder on the other side, where it is still farther expanded.

The cylinders are so proportioned that the work done in one equals as nearly as may be that done in the other. Since the work done in both cylinders is the same, the cylinder tractive power can be computed from Equation (3), page 138, by using the dimensions and pressure of either cylinder. It is usual to consider the high-pressure cylinder, and because of the necessary back pressure on the exhausting side of the piston head, to assume two thirds of the boiler pressure in computing the ultimate cylinder tractive effort. To determine the cylinder tractive effort under working conditions, the pressure must be determined by an indicator.

Four-cylinder compound locomotives have a pair of cylinders, high pressure and low pressure, on each side. The arrangement of the cylinders varies. A pair may be attached to the same connecting rod, one above the other, or tandem, — that is, one in front of the other, — or they may be one inside and the other outside the plane of the driving wheels attached to cranks at quartering angles, providing what is called a balanced locomotive.* To determine the ultimate cylinder tractive effort of the four-cylinder compound locomotive, Equation (3), page 138, is used with the high-pressure cylinder dimension and pressure as in the two-cylinder class, and the result multiplied by 2; or better, the same formula is used with two thirds boiler pressure for the high-pressure cylinder and one fourth boiler pressure for the low-pressure cylinder, and the results added.

Locomotive Types. — The modern demand for heavy trains and high speed requires great boiler capacity, and therefore heavy locomotives. The efforts to design heavy locomotives for both fast and slow speeds have resulted in a number of different types distinguished by the difference in arrangement of the running gear. There may be two or four front truck wheels, from two to ten driving wheels, and a single pair of trailing wheels supporting the fire box behind the drivers. The front truck wheels are wanting in a few types, as in locomotives used for switching and known as yard or shifting engines, and the trailing wheels are a recent addition. A locomotive with two front truck wheels,

* See Plate XII following.

four driving wheels, and a pair of trailing wheels, besides having a type name, will be known as 2-4-2 (two-four-two) type. The principal types in common use for train service are: —

AMERICAN TYPE	4–4–0	For many years the standard passenger and freight type.
COLUMBIA	2–4–2	A not very common recent passenger locomotive.
ATLANTIC	4–4–2	A standard modern fast passenger type.
MOGUL	2–6–0	Designed for freight and passenger service.
PRAIRIE	2–6–2	A modern passenger type.
TEN WHEEL	4–6–0	A standard freight type sometimes used for passenger service.
PACIFIC	4–6–2	Generally used for passenger service on heavy grade roads; used somewhat for freight service.
CONSOLIDATION	2–8–0	Heavy freight service.
MIKADO	2–8–2	Heavy freight service.
MASTODON	4–8–0	Heavy freight service.
DECAPOD	2–10–0	Sometimes built without truck wheels — freight service.
SANTA FÉ	2–10–2	Heavy freight service on mountain grades.

Besides these there is the Shay locomotive, in which all the wheels are driving wheels, the engines being vertical engines on the side of the locomotive, driving a shaft which is connected with the wheels by bevel gearing. This locomotive is in limited use on a few steep mountain grades.

A very recent locomotive is the Mallet articulated compound or duplex locomotive. As first built in this country for heavy-grade service on the Baltimore and Ohio Railroad, this locomotive had twelve driving wheels in two sets of six each, the front set on a swiveling truck and operated by the low-pressure cylinders, the rear set rigidly parallel with the locomotive axis and operated by the high-pressure cylinders. Recent modifications have resulted in the following wheel arrangements: 2–4–4–2, 2–6–6–2, 0–8–8–0, 2–8–8–2, 2–6–8–0, and 4–4–6–2. The latest American locomotive (1911) is a four-cylinder balanced simple 4–4–2 type. It is provided with a superheater and is said to show a high degree of efficiency. Most of the types named are shown in the following illustrations.

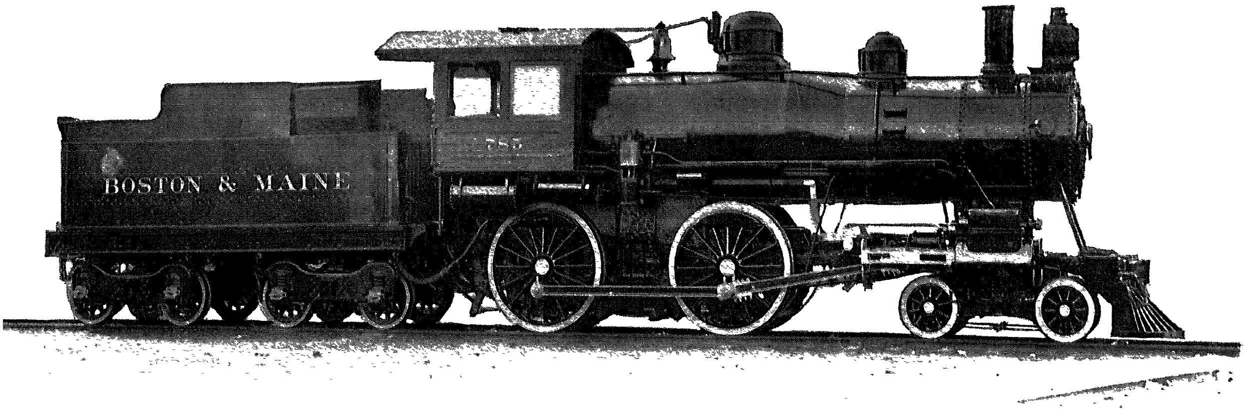


PLATE I

AMERICAN TYPE LOCOMOTIVE — FOR PASSENGER SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)

On driving wheels	75,240 lbs.
Total engine	118,030 lbs.
Tender (about)	86,000 lbs.

CYLINDER

Diameter	18 in.
Stroke of piston	24 in.

TENDER CAPACITY

Water	4000 U.S. gals.

WHEELS

Diameter of driving wheels	69 in.
Wheel base, Driving	9 ft.
Total engine	23 ft. 11 in.
Engine and tender,	48 ft. $6\frac{1}{4}$ in.

BOILER

Heating surface	1751 sq. ft.
Grate area	26 sq. ft.
Working pressure	190 lbs.

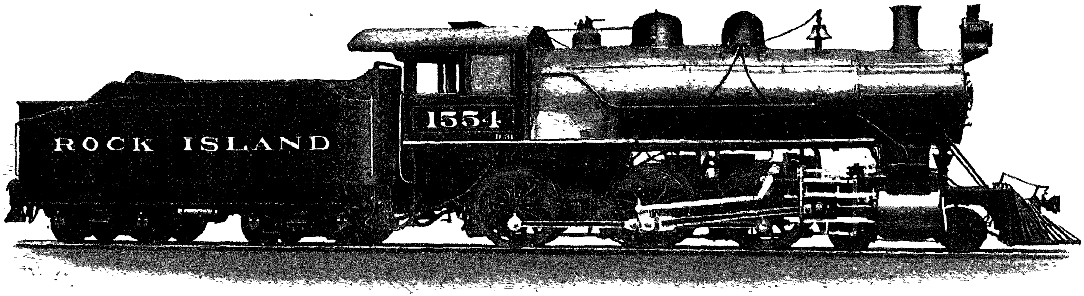


PLATE II

TEN-WHEEL LOCOMOTIVE—FOR FREIGHT SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)	
On driving wheels	131,200 lbs.
Total engine	173,720 lbs.
Tender (about)	130,280 lbs.
CYLINDER	
Diameter	22 in.
Stroke of piston	26 in.
TENDER CAPACITY	
Water	7000 gals.
Fuel	12 tons.
WHEELS	
Diameter of driving wheels	63 in.
Wheel base, Driving	15 ft.
Total engine	26 ft. 6 in.
Engine and tender	56 ft. 5½ in.
BOILER	
Heating surface	2586.8 sq. ft.
Grate area	44.9 sq. ft.
Working pressure	185 lbs.

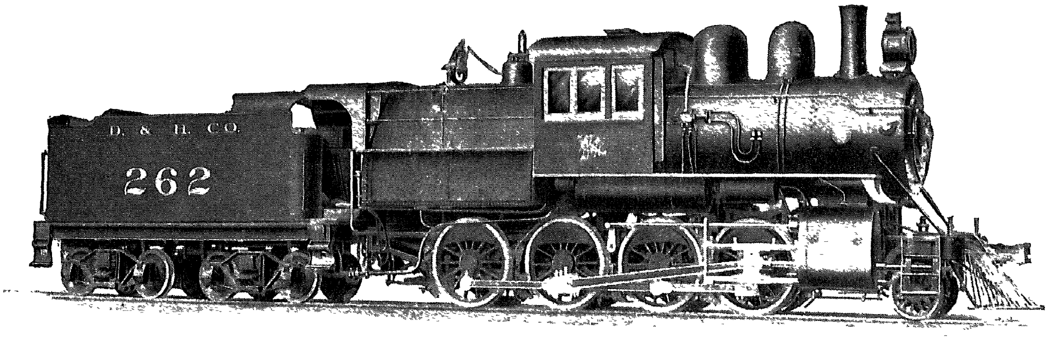


PLATE III

CONSOLIDATION TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

(American Locomotive Works)

WEIGHT (In service)	
On driving wheels	145,000 lbs.
Total engine	166,000 lbs.
Tender	106,000 lbs
WHEELS	
Diameter of driving wheels	56 in
Wheel base, Driving	16 ft. 2 in.
Total engine	24 ft. 2 in.
Engine and tender,	50 ft. 5 in.

CYLINDER	
Diameter	21 in.
Stroke of piston	26 in.
BOILER	
Heating surface	2446 sq. ft.
Grate area	85 sq. ft.
Working pressure	180 lbs.

TENDER CAPACITY	
Water	5000 gals.
Fuel	10 tons.
OUTSIDE DIMENSIONS	
Height above rail	15 ft.
Width	10 ft 2 in.
Length over all	60 ft. 3 in.

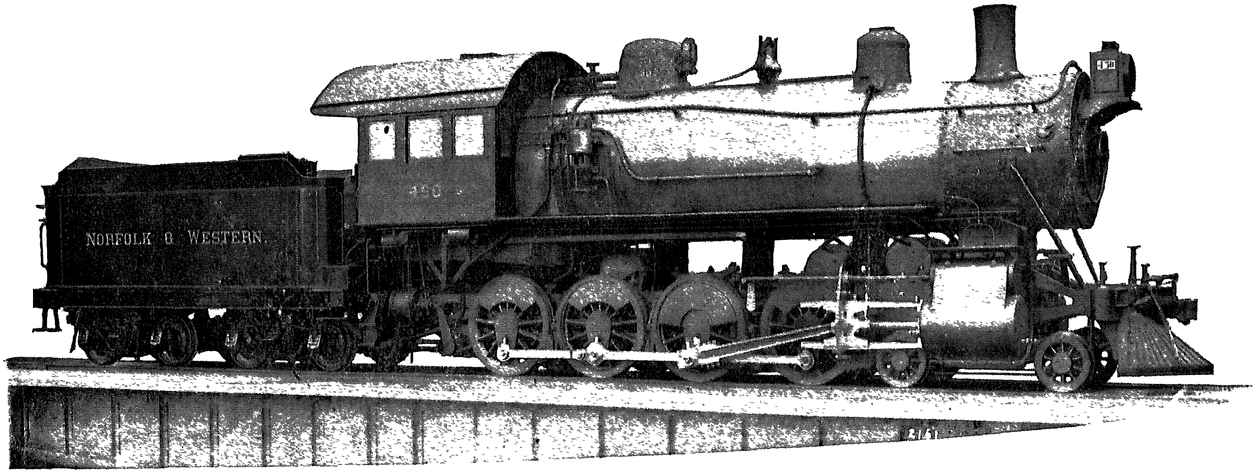


PLATE IV

TWELVE-WHEEL TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)
- On driving wheels .... 165,580 lbs.
- Total engine .... 199,200 lbs.
- Tender (about) .... 115,800 lbs.

CYLINDER
- Diameter .... 21 in.
- Stroke of piston .... 30 in.

TENDER CAPACITY
- Water .... 6000 gals.
- Fuel .... 10 tons.

WHEELS
- Diameter of driving wheels ..... 56 in.
- Wheel base, Driving .... 15 ft. 6 in.
- Total engine ...... 26 ft. 5 in.
- Engine and tender, 53 ft. 7 in.

BOILER
- Heating surface .... 2940 sq ft.
- Grate area .... 44.5 sq ft.
- Working pressure .... 200 lbs.

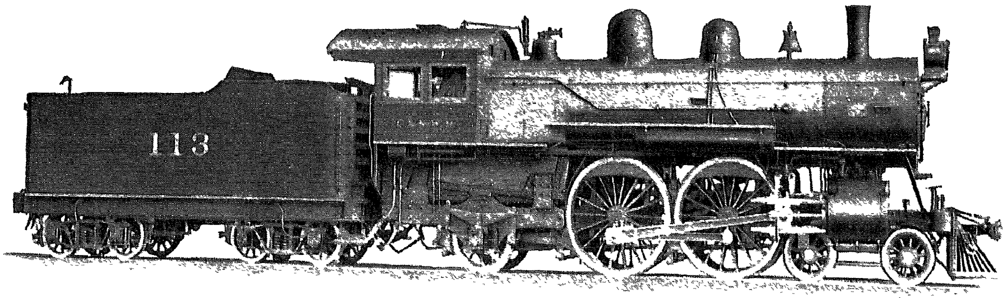


PLATE V

ATLANTIC TYPE LOCOMOTIVE — FOR PASSENGER SERVICE

(American Locomotive Works)

WEIGHT (In service)	
On driving wheels	92,500 lbs.
Total engine	172,000 lbs.
Tender	145,000 lbs.
WHEELS	
Diameter of driving wheels	81 in.
Wheel base, Driving	7 ft.
Total engine	26 ft. 9 in.
Engine and tender,	58 ft. 1 in.

CYLINDER	
Diameter	20 in.
Stroke of piston	26 in.
BOILER	
Heating surface	2970 sq. ft.
Grate area	46.3 sq. ft.
Working pressure	200 lbs.

TENDER CAPACITY	
Water	7500 gals.
Fuel	12 tons.
OUTSIDE DIMENSIONS	
Height above rail	15 ft. 2 in.
Width	9 ft. 9 in.
Length over all	67 ft. 6 in.

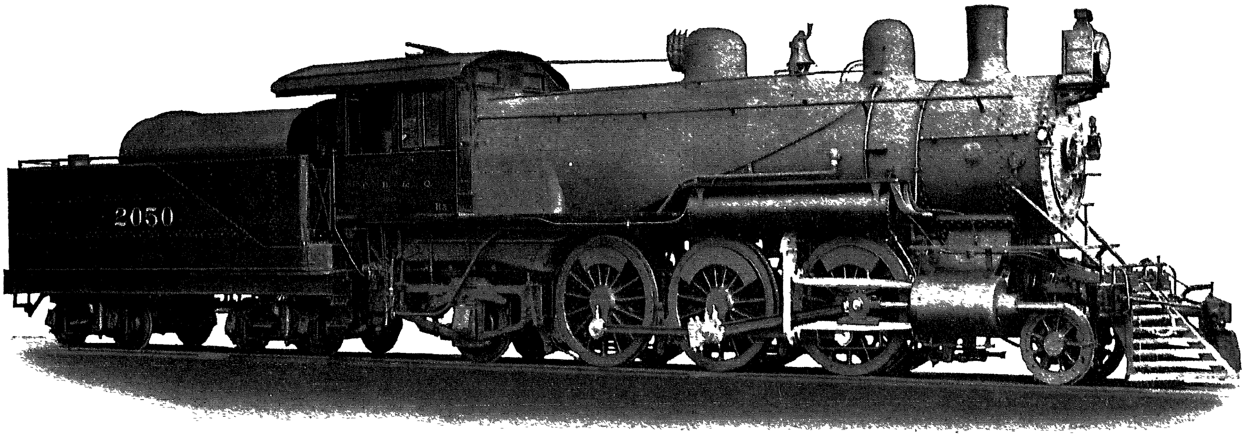


PLATE VI

PRAIRIE TYPE LOCOMOTIVE — FOR PASSENGER AND FREIGHT SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)	
On driving wheels	159,540 lbs.
Total engine	216,000 lbs.
Tender (about)	152,000 lbs.
CYLINDER	
Diameter	22 in.
Stroke of piston	28 in.
TENDER CAPACITY	
Water	8000 gal.
Fuel	16 tons.
WHEELS	
Diameter of driving wheels	69 in.
Wheel base, Driving	13 ft. 4½ in.
Total engine	30 ft. 8½ in.
Engine and tender,	62 ft. 2¾ in.
BOILER	
Heating surface	3560 sq. ft.
Grate area	55 sq. ft.
Working pressure	210 lbs.

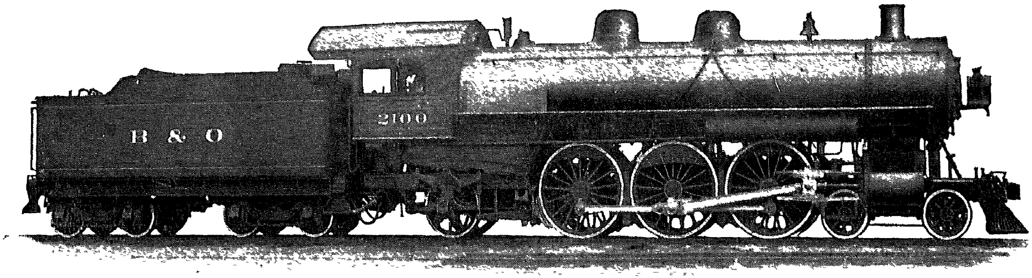


PLATE VII

PACIFIC TYPE LOCOMOTIVE — FOR PASSENGER SERVICE

(American Locomotive Company)

WEIGHT (In service)	
On driving wheels	150,500 lbs.
Total engine	229,500 lbs.
Tender	140,300 lbs.
WHEELS	
Diameter of driving wheels	74 in.
Wheel base, Driving	13 ft. 2 in.
Total engine	34 ft. $1\frac{1}{2}$ in.
Engine and tender,	65 ft. 3 in.
CYLINDER	
Diameter	22 in.
Stroke of piston	28 in.
BOILER	
Heating surface	3418 sq. ft.
Grate area	56.5 sq. ft.
Working pressure	200 lbs.
TENDER CAPACITY	
Water	7000 gals.
Fuel	12 tons.
OUTSIDE DIMENSIONS	
Height above rail	14 ft. 7 in.
Width	10 ft. 1 in.
Length over all	74 ft. 2 in.

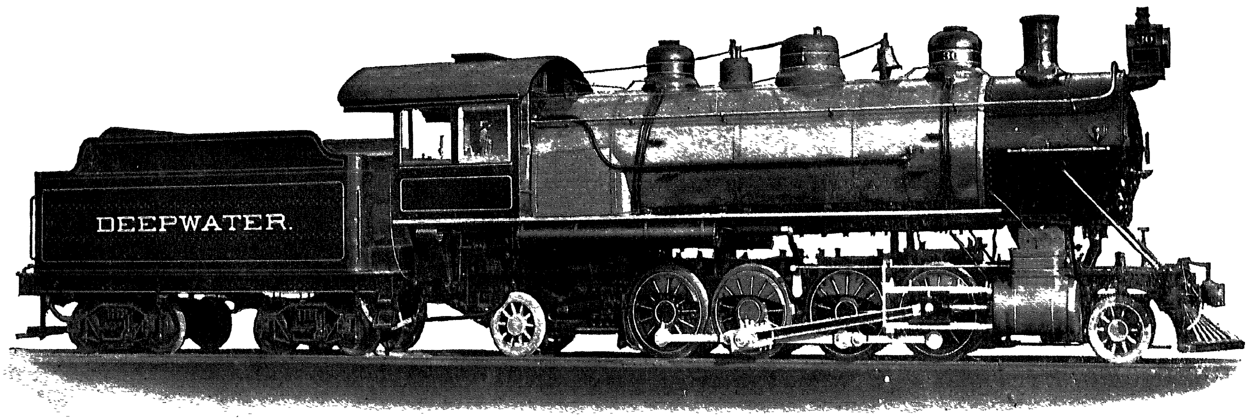


PLATE VIII

MIKADO TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)	
On driving wheels	174,400 lbs.
Total engine	217,300 lbs.
Tender (about)	118,700 lbs.
CYLINDER	
Diameter	22 in.
Stroke of piston	28 in.
TENDER CAPACITY	
Water	6000 gals.
Fuel	10 tons.
WHEELS	
Diameter of driving wheels	51 in.
Wheel base, Driving	14 ft.
Total engine	31 ft. 1 in.
Engine and tender	59 ft.
BOILER	
Heating surface	3414 sq. ft.
Grate area	51 sq. ft.
Working pressure	200 lbs.

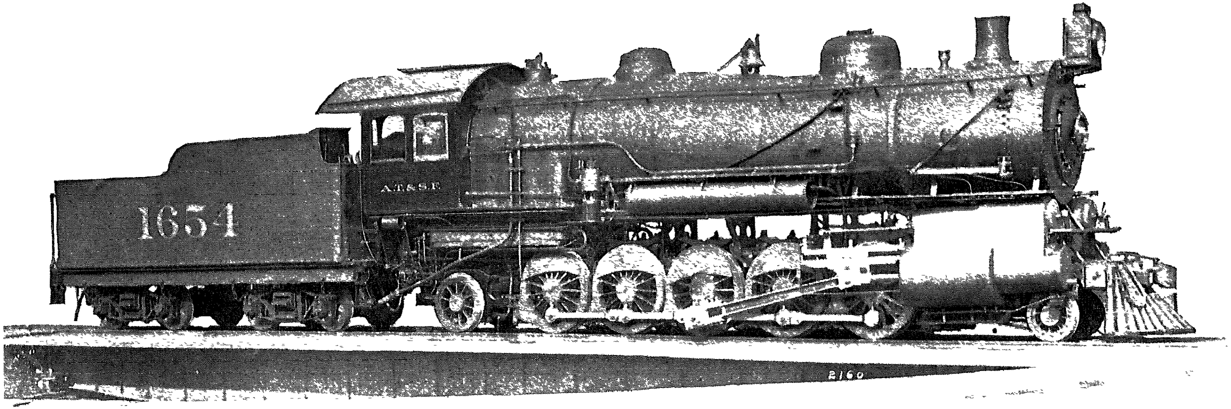


PLATE IX

SANTA FE TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

TANDEM COMPOUND

(Baldwin Locomotive Works)

WEIGHT (In service)
- On driving wheels.............. 234,580 lbs.
- Total engine.................. 287,240 lbs.
- Tender (about)............... 162,760 lbs.

WHEELS
- Diameter of driving wheels..... 57 in.
- Wheel base, Driving........... 19 ft. 9 in.
- Total engine...... 35 ft. 11 in.
- Engine and tender, 66 ft.

CYLINDER
- Diameter..................... 19 in. and 32 in.
- Stroke of piston.............. 32 in.

BOILER
- Heating surface............... 4796 sq. ft.
- Grate area................... 58.5 sq. ft.
- Working pressure . . . 225 lbs.

TENDER CAPACITY
- Water........................ 8500 gals.
- Fuel......................... 10 tons.

OUTSIDE DIMENSIONS
- Height above rail.............
- Width.... ....
- Length over all............... 77 ft. 10 in.

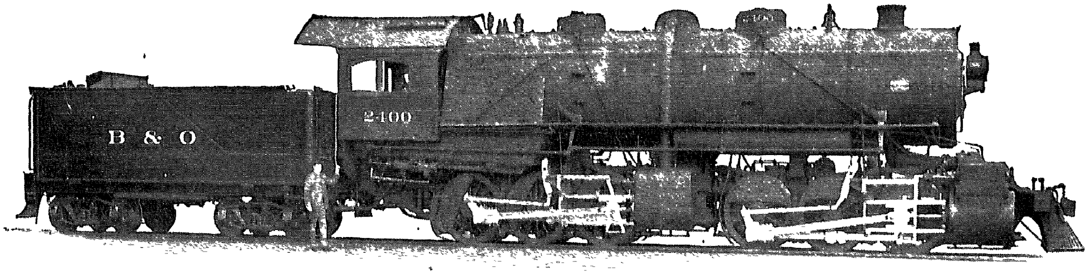


PLATE X

MALLET ARTICULATED TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

(American Locomotive Company)

WEIGHT (In service)
- On driving wheels .... 334,500 lbs.
- Total engine..... .... 334,500 lbs.
- Tender..................... 143,000 lbs.

WHEELS
- Diameter of driving wheels..... 56 in.
- Wheel base, Driving.......... 10 ft. and 10 ft.
- Total engine...... 30 ft. 8 in.
- Engine and tender, 64 ft. 7 in.

CYLINDER
- Diameter .... 20 in. and 32 in.
- Stroke of piston.............. 32 in.

BOILER
- Heating surface .... 5585.7 sq. ft.
- Grate area................... 72.2 sq. ft.
- Working pressure............. 235 lbs.

TENDER CAPACITY
- Water.. .. 7000 gals.
- Fuel... .... 15 tons.

OUTSIDE DIMENSIONS
- Height above rail. .... 15 ft.
- Width....................... 10 ft. 5 in.
- Length over all............... 79 ft. $6\frac{1}{2}$ in.

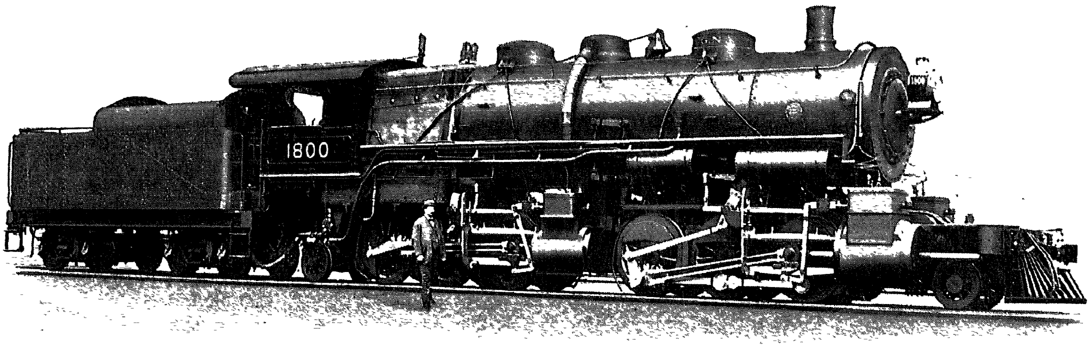


PLATE XI

MALLET ARTICULATED TYPE LOCOMOTIVE — FOR FREIGHT SERVICE

(Baldwin Locomotive Works)

WEIGHT (In service)

On driving wheels	316,000 lbs.
Total engine	355,000 lbs.
Tender	148,000 lbs.

CYLINDER

Diameter	21½ in. and 33 in.
Stroke of piston	32 in.

TENDER CAPACITY

Water	8000 gals.
Fuel	13 tons.

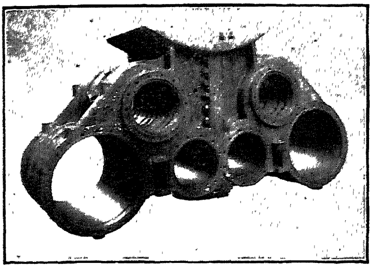
WHEELS

Diameter of driving wheels	55 in.
Wheel base, Driving	10 ft. and 10 ft.
Total engine	44 ft. 10 in.
Engine and tender,	73 ft. 2¼ in.

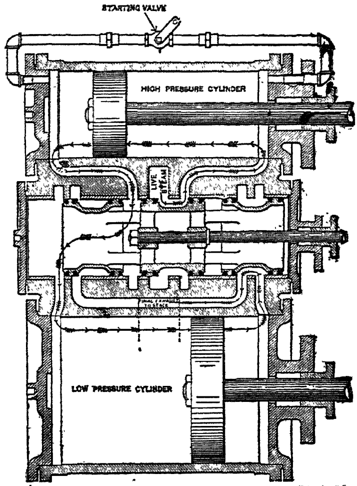
BOILER

Heating surface	5658 sq. ft.
Grate area	78 sq. ft.
Working pressure	200 lbs.

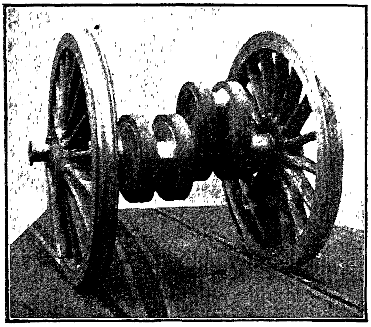
PLATE XII



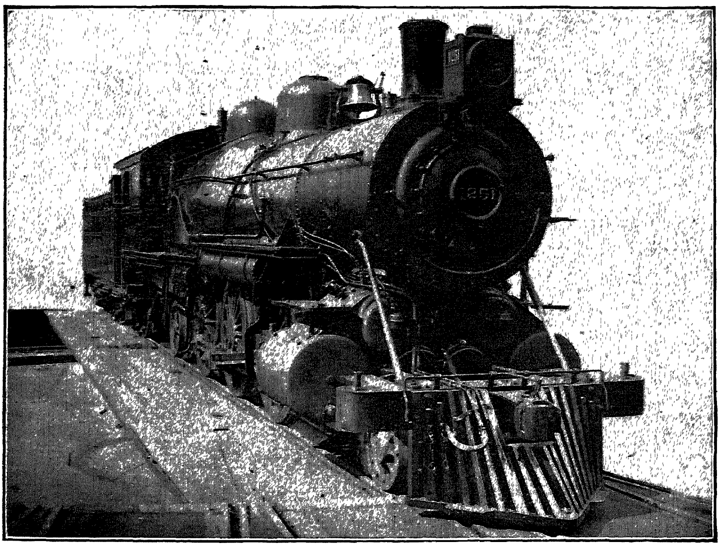
Cylinder Castings



STEAM DISTRIBUTION IN BALANCED COMPOUND CYLINDERS



Driving Wheels Showing Cranks



A Balanced Compound Locomotive

CHAPTER XII

THE WORK OF THE LOCOMOTIVE

The Work Classified. — In drawing a train a locomotive overcomes resistance by exerting a tractive effort equal to the resistance if the speed be constant, somewhat in excess of the resistance if the speed be accelerated, and somewhat less than the resistance if the speed be retarded or negatively accelerated.

The first condition, uniform velocity, is easily understood; the second condition exists in starting a train or in increasing its speed at any point except on a down grade where the action of gravity assisting the locomotive may make the necessary tractive effort of the locomotive no greater than that necessary for uniform motion, or even none at all; and the third condition may exist on an up grade, when gravity acting against the locomotive increases the resistances to be overcome beyond the tractive power of the locomotive and so retards the train, producing what may technically be called negative acceleration. If such an up grade be long enough the train will come to a standstill and then start back downhill against the effort of the locomotive unless brakes be set to hold the train; but if the grade be short, the only effect will be to reduce the speed which can be again increased on the succeeding, more favorable grade.

If a down grade be sufficiently steep and long, the speed will increase beyond what is safe unless the effort of the locomotive cease, and brakes be applied to increase the resistance until it equals the force of gravity down the grade, when the speed will remain uniform until the grade is passed. With power brakes this cannot be practically done, since no satisfactory type of brake has been devised to furnish a varying pressure at the will of the

operator. The resistances to be equaled in their sum by the tractive effort of the locomotive are: —

1. Resistance to motion at a constant velocity, on a straight and level track (train resistance).
2. Resistance to change of velocity (a resistance only when the velocity is to be increased).
3. Resistance offered by adverse grades.
4. Resistance offered by curves.

Resistance offered by the friction of the moving machinery of the locomotive is not included, because in this book it has been deducted in the derivation of final formulas for tractive effort. When formulas that give gross tractive effort are used, the engine friction must be included in the resistances to be overcome.

1. TRAIN RESISTANCE

Resistance to Motion at Constant Velocity. — Train resistance. Resistance to motion at a constant velocity, commonly, and hereafter in this book called train resistance, includes (1) journal friction; (2) rolling friction or resistance; (3) resistance due to oscillation and concussion; (4) head, tail, and side resistance of the atmosphere.

Journal friction is a maximum of 15 or 20 pounds per net ton at a velocity of 0 + just after starting from rest; it is not nearly so much when slowing down from motion to 0 + or after a momentary stop. From this maximum it falls rapidly as the velocity increases to an unknown minimum possibly approximating 2 pounds per ton. It is very much affected by temperature, and if a minimum of 2 pounds is realized in summer temperature, it is very probable that the minimum may be 4 to 6 pounds in winter weather. It varies very little with velocity if the speed is above 6 or 8 miles an hour. It depends very much on the character of the lubrication and the condition of the bearings.

Rolling resistance is unknown in amount and is usually classed with journal friction. It doubtless varies much with the condi-

tion of the track, and with the insistent weight, and is little affected by velocity changes. Rolling resistance and journal friction together are assumed at from 2 to 3 pounds per net ton in modern expressions for train resistance.

Resistance due to oscillation and concussion is unknown in amount, is believed to be very small, and probably varies with the square of the velocity.

Atmospheric resistance has been most thoroughly investigated by Professor Goss at the Purdue laboratory. Much depends on the form of the cars and the make-up of the train. A freight train of box cars moving through still air seems to be resisted by a force given by the expression $A = (0.13 + 0.01\,C)S^2$, C being the number of cars in the train. For the engine and tender alone $A = 0.11\,S^2$ and for the train alone $A = (0.016 + 0.01\,C)S^2$. For passenger trains the coefficient of C is to be doubled. At ordinary freight train speeds the whole quantity is small, but at high velocities the resistance is considerable, consuming from 10 to 20 per cent of the tractive force of the locomotive. The foregoing values are for motion through still air. A head wind of velocity equal to that of the train would increase the resistance four times, a side wind would have an unknown effect which would be quite large.

Summarizing all we know of train resistance, it is probable that the whole may be represented by an equation of the form

$$R = \left(A + BS + \frac{C}{(S+K)^2} + DS^2\right) W + MS^2,$$

in which R is the total resistance in pounds, A, B, C, D, K, and M are coefficients, some of which may be 0, to be determined by experiment, W the weight of the train in tons, and S is the speed in miles per hour. If MS^2 be omitted, then, since W is expressed in tons, the parenthesis gives the resistance in pounds per ton of train, which is the usual way of stating it.

The commoner formulas for train resistance are much simpler than that just given.

The Baldwin Locomotive Works formula is

$$R_t = 3 + \frac{S}{6},$$

in which R_t is resistance in pounds per ton of train and S is speed in miles per hour.

The *Engineering News* formula is

$$R_t = 2 + \frac{S}{4}.$$

These formulas make no allowance for the fact that loaded trains have a less resistance per ton than empty trains, and they also probably include the machine friction of the locomotive. In using these formulas in connection with the boiler tractive effort, the undiminished value of the tractive effort should be used,

namely, $$T = \frac{161\,H}{S} \text{ or } \frac{375\,I.H.P.}{S}.$$

Formulas that are perhaps better for freight train resistance are those devised by Mr. Sanford L. Cluett to fit the curves of the late Mr. A. M. Wellington; they are

$$\text{For empty trains } R_t = 5.4 + 0.01\,S^2 + \frac{70}{(S+.3)^2}.$$

$$\text{For loaded trains } R_t = 3.8 + 0.0076\,S^2 + \frac{16.4}{(S+1)^2}.$$

The formulas give results probably much too great for high speeds, and possibly somewhat too high for all speeds. The following modifications are suggested, and while less simple than the *Engineering News* or Baldwin formulas, they are believed to fairly well fit freight train resistance curves, not including machine friction, and are applicable for speeds of from 0+ to about 35 miles an hour.

$$\text{Loaded train } R_t = 3.5 + 0.0055\, S^2 + \frac{16}{(S+1)^2}. \qquad (1)$$

$$\text{Empty train } R_t = 5.0 + 0.007\, S^2 + \frac{8}{(S+1)^2}. \qquad (2)$$

These formulas will suffice for what may be called normal conditions. They do not include the effect of heavy head winds such as may prevail for considerable periods on the Western plains, nor do they show differences for different lengths of train except as this is taken care of by the weights of empty and loaded trains. For comparatively short trains with 100,000 pound capacity cars,

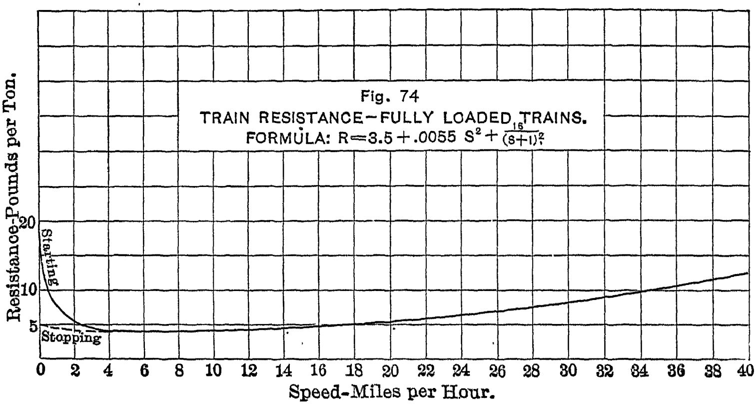


Fig. 74

the resistance would probably be slightly less than the formulas indicate, but the uncertainties are so great, the unknown and unknowable conditions so numerous, that it is believed the results of the formulas may be used with confidence if proper interpolation be made for partially loaded trains, and judgment allowances be made for trains working under abnormal conditions. The diagram of this equation for loaded trains will be found convenient for reference. A second curve is shown to the left of the minimum point of the main curve, to be used when the low speed is the

result of slowing down instead of starting from rest. The following table will be found useful: —

TABLE I

TRAIN RESISTANCE IN POUNDS PER TON

Computed from the formula $R = 3.5 + 0.0055\,s^2 + \dfrac{16}{(s+1)^2}$ for fully loaded trains.

For partially loaded trains multiply weight of cars by $1\frac{1}{2}$ and of load by $\frac{3}{4}$, and add for equivalent rating load for use with this table.

The upper figures in the first line represent resistance when slowing down or increasing slow speed, the lower figures the resistance when starting from rest.

Speed Miles per Hour	0+	½	1	1½	2	2½	3	3½	4	4½
0	5.00 19.00	4.44 10.61	4.36 7.51	4.30 6.07	4.25 5.30	4.20 4.84	4.16 4.55	4.12 4.36	4.09 4.23	4.06 4.14
10	4.18	4.23	4.28	4.33	4.38	4.45	4.51	4.58	4.65	4.73
20	5.74	5.84	5.96	6.07	6.19	6.31	6.44	6.58	6.70	6.82
30	8.47	8.64	8.81	8.97	9.14	9.32	9.50	9.68	9.87	10.06

Speed Miles per Hour	5	5½	6	6½	7	7½	8	8½	9	9½
0	4.04 4.08	4.03 4.05	4.03	4.01	4.02	4.03	4.05	4.08	4.11	4.14
10	4.80	4.88	4.96	5.05	5.14	5.23	5.32	5.42	5.53	5.63
20	6.96	7.10	7.24	7.38	7.53	7.68	7.83	7.99	8.15	8.30
30	10.25	10.44	10.64	10.84	11.04	11.24	11.45	11.66	11.87	12.09

Recently published reports suggest that train resistance is practically constant at less than 5 pounds per ton for speeds between 10 and 35 miles an hour, the reduction in journal friction offsetting the increase in velocity resistance. In the 1910 Transactions of the American Society of Mechanical Engineers appear results of experiments by Professor Edward C. Schmidt disproving this theory and furnishing what are probably the most reliable values for train resistance with modern trains. The following equation gives values closely agreeing with those of Professor Schmidt, except for trains of

empty gondola cars for which the formula values should be diminished about one pound for all speeds. The last term of the formula is used *only* for low speed when *starting*. In the formula W is the average weight per car of train.

$$R=\left(1.5+\frac{100}{W}\right)\left(1+\frac{S}{100}\right)+\frac{S^2}{125\sqrt{W}}+\frac{8}{(S+0.7)^2}.$$

This article and subsequent chapters depending on it will be rewritten in the next edition of this book.

2. RESISTANCE TO CHANGE OF VELOCITY

Accelerated Motion. — The resistance offered to change of speed is a definite quantity that can be determined with precision. The determination depends on certain simple principles of mechanics which will be stated.

By the property of inertia, all bodies tend to stay in that condition of motion in which at any instant they may be. An accelerating, retarding, or deviating force must be applied to change the condition of motion as to velocity or direction.

It is known that a constantly applied force of given magnitude will produce a uniformly changing condition of motion on any given mass. The rate of change is called the acceleration and may be positive or negative (retardation). It is known also that the acceleration of a given mass is proportional to the magnitude of the constant unbalanced force acting. Thus, if w be the weight of a body, that is, the measure of the force of gravity acting on it, and g be the acceleration due to gravity, and if P be any other force applied to the body, the acceleration a, produced by P, will be given by

$$\frac{a}{g}=\frac{P}{w} \text{ or } a=\frac{P}{w}g, \tag{1}$$

from which the force P necessary to produce the acceleration a in a body of weight w is

$$P=\frac{wa}{g}. \tag{2}$$

This force P may be considered the resistance to change of velocity for the rate of change a.

Under the influence of the force of gravity the velocity of a falling body increases g feet per second, g having a value varying with the distance from the center of mass of the earth and with latitude, but usually assumed for mechanical problems as 32.16. If the body start from rest, it will have a velocity of g feet at the end of the first second; its average velocity for the first second will therefore be $\frac{g}{2}$ feet, which will also be the space covered in the first second. At the end of t seconds the velocity will be tg feet per second, the average velocity will have been $\frac{tg}{2}$, and the space passed over will therefore be $\frac{tg}{2} \times t = \frac{t^2 g}{2}$ feet. If v be velocity in feet per second, t be time in seconds, and h the space or height of fall,

$$v = gt \tag{3}$$

$$h = \frac{gt^2}{2}. \tag{4}$$

Since from (3) $t = \frac{v}{g}$, substitution in (4) gives

$$h = \frac{v^2}{2g}. \tag{5}$$

Perfectly analogous to these equations, if P be a force acting on a body and producing an acceleration of a feet per second, for t seconds, covering a space of l feet

$$v = at \tag{6}$$

$$l = \frac{at^2}{2} \tag{7}$$

$$l = \frac{v^2}{2a}. \tag{8}$$

If a body be uniformly accelerated in a distance of l feet from rest to a velocity of v feet per second, the acceleration from (8) is

$$a = \frac{v^2}{2l}, \tag{9}$$

and the force P necessary to produce this acceleration, given by substituting for a in (2), its value from (9), is

$$P = \frac{wv^2}{2gl}. \tag{10}$$

If the velocity is expressed in miles per hour S

$$v = \frac{5280\,S}{3600}$$

and

$$P = \frac{w}{2gl} \times \left(\frac{5280\,S}{3600}\right)^2,$$

and if the weight is expressed in tons W of 2000 pounds

$$w = 2000\,W$$

and

$$P = \frac{66.9\,WS^2}{l}. \tag{11}$$

Train Acceleration. — If a train be the body, P is the tractive effort in pounds to be exerted by the locomotive on a train of W tons including the locomotive, to produce the velocity of S miles per hour in the distance of l feet, starting from rest.

But not only is the train given a velocity of translation, the wheels are given a velocity of rotation, requiring P to be larger than indicated by the foregoing expression by an amount depending on the relative masses of car and wheels, the pattern of the wheels, and the velocities. For any given set of conditions the addition to P may be determined by comparing the energy required to accelerate the car wheels in their motion of rotation with that required to give the resulting motion of translation to the car as a whole. No great precision can be attempted for a

general formula. The increase of P may be as little as $2\frac{1}{2}$ per cent, and it may be as high as 6 or 8 per cent over that given by Equation (11). Adopting 4.63 per cent for simplicity of result

$$P = 70 \frac{S^2}{l} W. \tag{12}$$

This force P must be in excess of the forces necessary to overcome all other resistances.

It is probable that no train is uniformly accelerated from rest to any given velocity it may attain, because from a velocity of 0+ to 5 or 6 miles an hour the pull an engine exerts is nearly constant and is the tractive effort of adhesion,* while the resistances to motion rapidly decrease, leaving an increasing portion of the tractive effort for acceleration. When the velocity of 5 or 6 miles is exceeded, the resistances to motion slowly increase, the tractive effort decreases, and there results a decreasing force available for acceleration, decreasing somewhat more rapidly than in proportion to the increase of velocity.

If the velocity is to be increased from S_1 miles per hour to S_2 miles per hour, the force required is

$$P = 70 \frac{W}{l} (S_2{}^2 - S_1{}^2). \tag{A}$$

* This statement may be questioned. The Pennsylvania Railroad testing department, in its estimates of maximum tractive effort of simple locomotives, counts on only 80 per cent of the boiler pressure as available in the cylinders even at mimimum speeds. If this allowance is correct, probably no simple locomotives in common use can ever exert their full tractive effort of adhesion, which is usually estimated to be as high as one fourth of the weight on the drivers for favorable conditions of track, and not usually lower than one fifth under quite unfavorable conditions.

The Baldwin Locomotive Works states that the initial pressure in the cylinder may vary from full boiler pressure at very slow speeds to 85 per cent of boiler pressure at high speeds of 300 revolutions per minute, and uses rather better than 90 per cent of the initial pressure when the speed is less than 50 revolutions per minute, indicating that the full tractive effort of adhesion may be realized by the cylinders at very slow speed. Road tests have been made in which one third the weight on the drivers has been realized as tractive effort.

Further road tests are perhaps necessary to establish the facts. The locomotive testing plants thus far devised are not adapted to tests of high tractive effort at slow speed.

If the force be known, and it is desired to determine the distance required to increase the velocity from S_1 to S_2 miles per hour,

$$l = 70\frac{W}{P}(S_2{}^2 - S_1{}^2). \tag{B}$$

If the distance and available force are known, and it is desired to know how great a load can be carried with the required acceleration, A or B is solved for W giving

$$W = \frac{Pl}{70\ (S_2{}^2 - S_1{}^2)}\cdot \tag{C}$$

If W, P, l, and S_1 are known and S_2 is desired, A or B is solved for S_2 giving

$$S_2 = \pm\sqrt{\frac{Pl}{70\ W} + S_1{}^2}\cdot \tag{D}$$

In determining l, since P can never be constant, nor even approximately constant, through any considerable change in speed, it is not uncommon to find l for a change in speed of 1 mile per hour, using successively S_1, $S_1 + 1$, $S_1 + 2$, etc., as initial speeds, until the required change is reached, when the sum of the several values of l will be the distance required. If $S_2 = S_1 + 1$, Equation (B) becomes

$$l = 70\frac{W}{P}(2\ S_1 + 1). \tag{E}$$

The load W in any problem likely to arise would be known or estimated. The available tractive effort P must be estimated by subtracting from the estimated total tractive effort of the locomotive, the resistance due to such grade as the train may be on, and the ordinary train resistance. Equation (A) gives the resistance due to acceleration, or change of speed, or what is the same thing, the force necessary to produce acceleration.

3. GRADE RESISTANCE

Grade Resistance. — The resistance to the progress of a train offered by a grade is due to the action of gravity which tends to pull the train down the hill. The work done in lifting a train through any number of vertical feet r, equals the weight of the train times the number of feet lifted. The work is the same whether the train be lifted vertically or on an incline of length l.

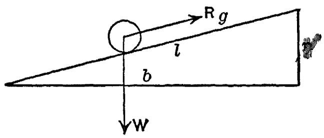


Fig. 75

Since the work is the same — that is, the work of lifting — not including the work of rolling along the track, and since work is force times distance, the force R_g, required on the grade, times the length of the grade equals the weight times the rise; or

$$Wr = R_g l$$

whence

$$R_g = W\frac{r}{l}.$$

In railroad grades the grade angle is small and the base length of the grade does not differ much from the inclined length; and since it is the base length that is obtained in surveys, it is customary to say that

$$R_g = W\frac{r}{b}.$$

When b is one station, 100 feet, r is the rate per cent of the grade; and if W be one ton of 2000 pounds, then R_g in pounds per ton may be expressed by

$$R_g = \frac{2000 \times \text{rate per cent of grade}}{100}$$

$$R_g = 20 \times \text{rate per cent.}$$

This is the standard formula for grade resistance and gives pounds resistance per ton of train on any grade.

4. CURVE RESISTANCE

General Statement. — Curve resistance is the resistance offered at the draw-bar to motion along a curved track over and above that offered by a straight track.

No entirely satisfactory theoretical discussion of curve resistance has been published. Experiments have been made showing that with high-degree curves the resistance is about 0.4 pound per ton per degree for American bogie trucks of about 5 feet wheel base at slow speed; that it is considerably more than this for curves of small degree and long rigid wheel base, even reaching 1.5 pounds per ton per degree. The usual allowance made by locating engineers in America is from 0.8 of a pound to 1 pound per ton per degree. This is perhaps not much too large for low-degree curves, is certainly not too large for a long-wheel base on a curve of low degree, but is too large for 5 or 6 foot trucks on sharp curves. Observation has seemed to show that the resistance per degree is greater on flat curves than on sharp curves. An attempt to discuss the action of a truck on a curve and to develop a rational theory for curve resistance that shall agree with observation will be made.

Relation of Wheel and Rail. — Car wheels are slightly coned, $\frac{1}{16}$ inch in $2\frac{3}{8}$ inches, the tread joins the flange by a fillet curve

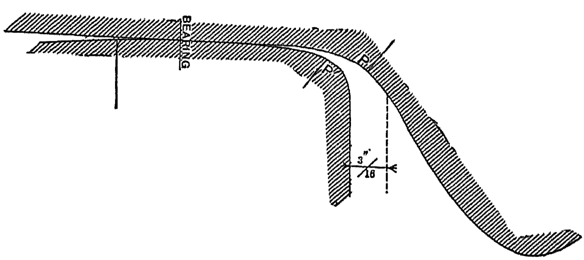


Fig. 76

of $\frac{5}{8}$-inch radius, the flange is not straight at any point, but is curved. The fit of a new wheel and rail is shown in Fig. 76.

The corner of an American Society of Civil Engineers' rail section is rounded with a $\frac{5}{16}$-inch radius, and between the gauge side of the rail and an arbitrary point in the fillet curve of the wheel flange there is a space of $\frac{3}{16}$ inch, giving a so-called $\frac{3}{8}$-inch play between the gauge of the wheels as set on the axles and the gauge of the track. With engine drivers a larger allowance is made, up to $\frac{7}{8}$ inch. Owing to the coning of the wheel and the 12-inch curve of the rail top, the wheel bears on the rail as indicated in the figure; and if moved over toward the rail about $\frac{3}{32}$ inch, a point on the fillet curve would come into bearing well up on the top of the corner curve of the rail. If the wheel be moved still farther against the rail until the $\frac{3}{16}$-inch play is used up, then the wheel would be lifted about $\frac{1}{16}$ inch off the rail top and would be bearing at about the points P and P′ in the figure. It is doubtful if the gauge point in the flange of a new wheel ever comes into bearing on a new rail. The inside corner of the outside rail of a curve gradually wears down to fit the curve of the flange, which may then have a large bearing on the rail. The forward outside wheel of a truck rounding a curve bears against the outside rail; but the foregoing discussion will show the practical difficulty of determining the point of bearing. The irregularities of track, variable condition of rail and wheel as to wear, and unknown small forces, produce irregularities in the bearing point.

The bearing of a wheel on a rail is not in a point or line but in a surface due to the compressibility of the materials. This surface is small and of irregular shape, and variable in size with conditions and characteristics of materials. As an average the surface does not exceed in area the area of a circle of $\frac{3}{8}$-inch diameter, possibly somewhat larger under engine drivers.

Action of a Truck on a Curve. — Let a four-wheel truck of length a between axle centers be considered. The truck pulled by the force P, Fig. 77, acting at the center pin approaches the curve. As soon as the draw-bar reaches the curve the direction of pull P changes to a tangent to the curve at the draw-bar. The truck rolls straight ahead, however, until the forward outer flange

comes against the outer rail, when the resistance R with an equal force, component of P, at the center pin tends to skew the truck across the track and bring the rear inner wheel against the inner rail. How far over the inner wheel is drawn may not be known; apparently the flange does not wear against the side of the rail. The twisting movement is resisted by the normal pressures Q. If the truck is short, and the degree of curve small, the whole truck will be on the curve before the outer rail bears on the outer front flange, but if the truck be long, or the curve sharp, the forward wheel will strike the outer rail while the rear wheels are still on the tangent. Assuming that the whole gauge play is used up in skewing the truck, and that it varies from $\frac{3}{16}$ to $\frac{3}{8}$ inch, the angle between the rail and forward wheel will be from 0 degree 12 minutes to 0 degree 24 minutes when a 5-foot truck is wholly on a 1-degree curve, about twice these values for a 10-degree curve, and three times for a 20-degree curve. If the outer rail bears against the flange of the front wheel at a point in the vertical through the axis of the wheel, the rear axle should stand radial when the angle subtended by a chord of twice the wheel base is sufficient to give a middle ordinate for the outer rail equal to the gauge play; and both outer wheels should bind on the outer rail, the axis of the truck being then a chord to the curve, when the angle subtended by a chord of the wheel base gives a middle ordinate equal to the gauge play. But the bearing point is not in a vertical through the axis and it cannot be readily determined. The front and rear trucks probably do not act alike, since the forces applied to their respective center pins probably make different angles with the truck axes. The forward truck only will be considered, and the rear truck assumed to produce an equal resistance. As the truck is advanced by the pull P, it must be turned about some center through the central angle of the curve traversed. It makes no difference what that center is so far as

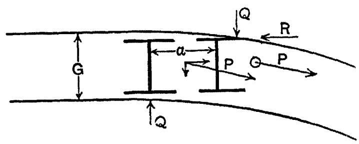


Fig. 77

the result of the discussion is concerned, and it will be assumed to be the rear inner wheel. Of course it is the center pin about which the truck turns, but at any instant the center may be assumed to be the rear inner wheel, since the center pin is moving with the truck. If there is no friction between wheel tread and rail, and if the speed through the curve is that for which the track is canted, there will be no curve resistance, since the canting of the track would counteract the centrifugal force and the truck would roll and slide around the curve with little flange pressure on the outer rail. But there is friction between rail and wheel tread, and the truck must be twisted against this friction. This twisting, with the losses in transmitting mechanism, causes curve resistance.

Theory of Curve Resistance. — Curve resistance arises from the slipping of the wheels on the rail. The total slipping for any curve is that due to twisting the truck through an angle equal to the change in direction, that is, the central angle of the curve.

If the wheels were loose on the axles so they could turn independently of one another, the outer wheel, revolving faster than the inner wheel, could travel the greater length of the outer rail while the inner wheel should run the lesser length of the inner rail, the axle being at all times radial to the curve, and there would be no longitudinal slip. But the wheels are rigidly attached to the axle, and one can turn no more than the other; hence, since the rails are of unequal length, the outer wheel must slip forward, or the inner wheel must slip backward, or both must slip a total amount equal to the difference in the lengths of the rails. If both axles were independent and could swivel, each about its own center to maintain a radial position, and if this radial position could be maintained, there would be no lateral slipping across the rails. But the axles are held parallel in a rectangular frame which must be revolved, and the circular motion of the frame will produce a lateral slip, as will be evident. In moving from A to B, Fig. 78, the truck frame must move longitudinally through the distance $l + a$ (a may be neglected), and must twist through the angle Δ. If the truck be considered to be revolving at every instant about its rear inner wheel, the rear outer wheel will be

sliding longitudinally with reference to the track, the forward outer wheel both longitudinally and laterally (diagonally), and

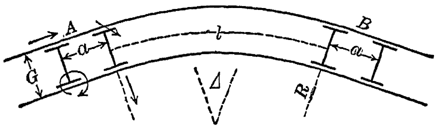


Fig. 78

the forward inner wheel only laterally. The rear inner wheel will be twisting on its rail. The force directly responsible for turning the truck is the pressure of the outer rail against the front outer wheel flange, and this force is induced by the pull on the draw-bar. What has preceded concerning the fit of wheel and rail, the uncertain gauge play, and irregularities of track conditions, will make evident the great difficulty, not to say impossibility, of completely analyzing and following all the forces involved in the final force at the draw-bar,* which may be called curve resistance. The principle of equal work will therefore be used, the work done in sliding the wheels being equated to the work done in overcoming curve resistance through the length of the curve, and that resistance determined. In radians the angle $\Delta = \frac{l}{R}$ and any point moving through an equal angle with a radius of r will move through an arc of $r \times \frac{l}{R}$. The two outer wheels will therefore slip longitudinally through an arc of $G \times \frac{l}{R}$, which is the difference in length of the two rails, and the two forward wheels will slip through an arc of $a \times \frac{l}{R}$. One half the weight of truck and load, therefore, slips $G\frac{l}{R}$ feet, and one half slips $a\frac{l}{R}$ feet. The resistance to slipping is the weight slipped

* Attempts to analyze the forces for locomotive wheel systems, to get the pressure on the outer rail, have been made by the New York Central & Hudson River Railroad engineers and by the editorial staff of the *Railroad Gazette*. See *Railroad Gazette*, March 15 and 22, 1907.

times the coefficient of friction. The coefficient is probably never greater than $\frac{1}{4}$, nor less than $\frac{15}{100}$, and may fairly be taken at $\frac{1}{5}$ as an average. For each ton of weight, therefore, a half ton times f, the coefficient of friction, will be the resistance to both longitudinal and lateral slipping; and work being force times distance, the work done in sliding the wheels will be for each ton of 2000 pounds

$$1000 \times f \times (G + a)\frac{l}{R}.$$

If x be the curve resistance at the draw-bar due to this sliding, the work done by x in the length l is $x\,l$. Equating these two expressions for work, and solving for x

$$x = \frac{1000\,f(G+a)}{R}.$$

If $\frac{5730}{D}$ be substituted for R,

$$x = \frac{1000\;f(G + a)D}{5730}.$$

The twisting of the rear inner wheel will increase the work done by perhaps $\frac{1}{40}$ of 1 per cent, and is neglected. The distance across the track between wheel bearings which must be used for G is probably about 4.80 feet. Using this value and $\frac{1}{5}$ for f

$$x = (0.168 + 0.035\,a)D.$$

If a be 5 feet, x is $0.34\,D +$.

But this is not the whole of curve resistance. It is the whole except that due to the friction of what may be called the transmitting mechanism between wheel and draw-bar. This friction is practically all at the bearing of the front outer flange and rail. The pressure of the flange against the rail is essentially constant and just sufficient to slide the three wheels. With the lever arms of these wheels considered, using $\frac{1}{5}$ as the coefficient of sliding

friction, the pressure will probably vary with the wheel base, and may be from 220 to 250 pounds per ton of total load, the smaller pressure for a 20-foot wheel base. This pressure times some coefficient of friction is a force to be overcome. The sliding here is not longitudinal along the rail, but is vertical or inclined, grinding down the corner or side of the rail. Just how much the sliding is cannot be told, but it occurs at a point a little in advance of a vertical through the center of the wheel, and the resisting force may be said to act with a lever arm of this slight advance, and to be overcome by a force acting at the center of the wheel, which force would be almost equivalent to that portion of curve resistance due to this cause. The lever arm of the frictional resistance cannot be exactly determined, nor will it be always the same. It is probably not less than $\frac{1}{8}$ inch nor more than $\frac{1}{4}$ inch with 33-inch wheels. If it is assumed to be $\frac{3}{16}$ and the coefficient of friction be assumed at $\frac{15}{100}$, — the slipping is much faster than that across the rail, and hence a smaller coefficient should be used, — the resulting curve resistance due to this flange friction may be from 0.41 pounds per ton for a 5-foot wheel base to 0.38 pounds per ton for a 20-foot wheel base. It will be observed that this resistance is independent of the degree of the curve. What may be considered equivalent to an increase of the friction coefficient will probably result from an increase of the angle between wheel and rail. It has been stated that this angle for a 10-degree curve is about twice that for a 1-degree curve. If it be estimated that the friction is increased in proportion to the increase in this angle, and the value $\frac{15}{100}$ be used for 1-degree curves, then for any curve this item of resistance is given by

$$y \text{ for } \quad 5\text{-foot truck} = 0.41 + 0.041\,D$$
$$y \text{ for } 20\text{-foot truck} = 0.38 + 0.038\,D.$$

Considering the very large element of uncertainty in the friction coefficient, and the lever arms of the forces, it will be sufficient to say that for all trucks

$$y = 0.4 + 0.04\,D.$$

Summing the two items of curve resistance developed, there results for curve resistance in pounds per ton of total load

$$R_c = x + y = 0.4 + (0.21 + 0.035\,a)D. \qquad (1)$$

For several round number wheel bases, closely approximating standard practice, the resistances would be

Wheel Base — feet	Resistance — pounds per ton	
5	$0.4 + 0.385\,D$ —	.332
6	$0.4 + 0.420\,D$ —	.345
7	$0.4 + 0.465\,D$	.3[illegible]
8	$0.4 + 0.490\,D$	37[illegible]
9	$0.4 + 0.525\,D$	[illegible]
12	$0.4 + 0.630\,D$	436
13	$0.4 + 0.665\,D$	452
15	$0.4 + 0.735\,D$	486
16	$0.4 + 0.770\,D$	503
20	$0.4 + 0.910\,D$	570

The materially greater resistance of locomotives is seen from this table. It will also be seen from the introduction of the constant term, that the resistance per degree is less with sharp than with flat curves. The results obtained by the use of these formulas agree very well with the results of experiment, both foreign and American.

The formulas omit any increase due to obliquity of traction because there is no such increase from one car to another. It is true that the axes of coupled cars do not lie in the same line, but the junction points of both couplers are moving in the same line which at any instant is a tangent to a curve concentric with the track curve and of slightly greater radius. The pull and resistance here therefore are in this tangent line. It is true that this pull acting at the following center pin is not in the line of action of the resistance at the wheel, but this has been considered

in the first item of resistance in the equation of work from which the tangential pull was derived, and in the second is presumably included in the friction allowance, which increases with the degree of the curve. The larger wheels of the locomotive probably do not reduce the second item of resistance, because it is probable that both lever arms are increased in the same ratio.

It is probable that the result of the formulas should be somewhat increased for very slow velocities, and possibly diminished for very high velocities, since the coefficient of sliding friction varies with the velocity of sliding. The sliding represented by the x term varies in speed with the speed of angular motion, and at a constant speed through the curve is ten times as fast for a 10-degree curve as for a 1-degree curve, and it also varies with the speed through the curve. For high-speed passenger trains it may be worth while to affect the formulas given by a coefficient for variation in speed, and the following form is suggested, C being the parenthesis of Equation (1).

$$R_c \text{ (passenger trains)} = (0.4 + CD)\left(1 - \frac{S - 20}{200}\right) \qquad (2)$$

While the resistance doubtless varies with all trains and with all speeds, the variation is thought to be too uncertain to warrant any alteration of the formula for freight trains.

This discussion divides the slip of the forward outer wheel into two parts. It is really but one slip,— diagonally on the round corner of the rail,— but it has been divided in the discussion to try to show the probable form of the curve resistance equation. It is believed the form is approximately correct, though experiment may indicate other values for the constants. The discussion neglects the momentary lateral pressure occurring at the beginning and end of a curve.

Resistances Compared. — It is convenient to compare the various resistances with grade resistance, the most definite and readily determined of the several resistances.

The curve of train resistance for fully loaded trains shows values about as follows: —

Speed in miles — per hour	0+	1	5	10	20	30
Resistance — pounds per ton	19.0	7.5	4.08	4.16	5.73	8.47
Equivalent grade — per cent	0.95	0.375	0.204	0.208	0.2865	0.4235

The equation for curve resistance, considering a 5-foot truck, gives values about as follows: —

Degree of curve	1	2	4	6	10	24
Resistance — pounds per ton	0.785	1.170	1.94	2.71	4.25	9.64
Equivalent grade — per cent	0.03925	0.0585	0.097	0.1355	0.2125	0.482

If a 13-foot engine truck be considered, the resistances are about as follows for the curves given: —

Degree of curve	1	2	4	6	10	24
Resistance — pounds per ton	1.065	1.73	3.06	4.39	7.05	16.36
Equivalent grade — per cent	0.05325	0.0865	0.153	0.2195	0.3525	0.818

The expression for the force necessary to produce acceleration at a uniform rate gives the following values for the accelerations noted to be acquired in the distances given:

Acceleration — miles per hour	0 — 1		1 — 2		2 — 4		4 — 10		10 — 20		20 — 30	
Distance in which acquired — feet	5	10	15	30	60	120	420	840	1500	3000	2500	5000
Resistance — pounds per ton	14.0	7.0	14.0	7.0	14.0	7.0	14.0	7.0	14.0	7.0	14.0	7.0
Equivalent grade — per cent	0.7	0.35	0.7	0.35	0.7	0.35	0.7	0.35	0.7	0.35	0.7	0.35

Suggestions. — The comparison of resistances to be overcome by the locomotive leads to the following suggestions: —

1. Since the minimum train resistance occurs at speeds of from 5 to 7 miles an hour, a speed within these limits would seem to be the proper speed to use in climbing ruling grades, both in practice and in computing. Ten miles is the speed most commonly assumed for computations as the lowest to be safely used; and while the author has seen many a long hill mounted at a less speed, it is perhaps wise to use the greater speed to give a safety factor when computing what a locomotive will probably be able to do.

2. It will be noted that grades of about 0.3 to 0.35 per cent will double the resistance of loaded trains to motion on straight and level track at good freight train speed, and that a curve of from 12 to 18 degrees will offer about the same resistance to car trucks, while a curve of from 8 to 10 degrees will similarly affect the locomotive. Considering the modern heavy locomotive, it is perhaps fair to say that a 10-degree curve about doubles the train resistance.

3. If an acceleration from rest to 20 miles an hour is required in 2000 feet, a resistance of 14 pounds per ton must be overcome equivalent to the resistance of a 0.7 per cent grade, while if 4000 feet may be used, the resistance is 7 pounds per ton, or that of a 0.35 per cent grade. These grades are therefore virtually added to the actual profile, whatever they may be. In addition to these grades there is added the virtual grade corresponding to the increased train resistance at starting. Assuming that the cars are started one at a time until a speed of 1 mile an hour has been reached, or until the train resistance has dropped to 10 pounds per ton, the excess resistance over that of, say, 10 miles an hour on the ruling grade, is approximately 6 pounds per ton, or the resistance of a 0.3 per cent grade. Assuming that the train may be started at the slower rate given above, at least at the beginning, while the train resistance is high, the total added grade due to high resistance and acceleration is 0.65 per cent. This discussion indicates, (*a*) the desirability of making stations on grade summits rather than in grade sags, or on level stretches at the foot of

a hill; (*b*) the absolute necessity of reducing ruling grades out of stations by from 0.30 per cent to 0.7 per cent, according to the ruling grade and the rate of acceleration desired, unless all maximum trains may be started by the aid of pushers; (*c*) the futility of spending money to secure ruling grades of less than about 0.35 to 0.4 per cent, except for handling fast trains, and unless all maximum trains may always be started by the aid of pushers or on a descent, conditions not likely to obtain.

Widening Gauge on Curves. — It is customary to widen the gauge on curves. Many formulas have been produced to show that the gauge on the sharper curves should be widened, and the amount of this widening. After carefully examining all of the formulas that have come to the author's attention, he has rejected all of them as theoretically incorrect, and has been unable to devise a formula that shall correctly give the widening of gauge necessary on curves. The necessary widening is less than is usually assumed, and is very small (nothing for car trucks), depending on the unknown position of the locomotive wheels on the rails. Conservative American practice widens the gauge on no curves under from 4 to 6 degrees. For sharper curves the widening is at the rate of $\frac{1}{16}$ inch per degree, with a maximum widening of $\frac{1}{2}$ inch on roads of moderate curvature and $\frac{3}{4}$ to 1 inch on roads of excessively sharp curvature.

Curve Compensation. — It is customary to offset curve resistance on heavy grades, and on all grades where the combination of curve resistance and grade resistance would more than equal the grade resistance of the ruling grade of the road or division, by reducing the grade. Thus, if a curve occurs on the ruling grade, that grade would be reduced through the curve by a grade of resistance equivalent to that of the curve. If a curve occurs on a minor grade, the grade would be reduced only enough to make the resulting total resistance equal that of the ruling grade. Of course no change is possible on a level. On a crooked road of very light gradients, such as the New York Central from New York to Albany, a practically level stretch for 150 miles, curve compensation is impracticable, the curves being in effect the

ruling grades. Since they are short, they could be operated as momentum grades, were it not desirable to traverse any one curve at a uniform speed. The usual allowance in compensating on ruling grades is from 0.04 to 0.05 per cent per degree of curvature. An investigation of the proper compensation for varying rates of grade based on the previously derived expressions for curve resistance will be made.

Let three ruling grades be considered, — 0.5 per cent, 1.0 per cent, and 2.0 per cent. Let there be a 5-degree curve long enough to hold an entire train, and let the train be a fully loaded, maximum train for a 10-wheel locomotive of the following dimensions:—

Cylinders	19 × 26 inches
Working pressure	190 pounds
Heating surface	2164.9 square feet
Diameter of drivers	54 inches
Weight on drivers	104,340 pounds
Rigid wheel base	12 feet
Total weight of engine and tender	240,000 pounds

At 10 miles an hour, on the three grades considered, if the track is straight, this locomotive can haul the following loads behind its tender: —

Grade — per cent	0.5	1.0	2.0
Load — tons	1722	960	470
In cars, say,	40	22	11

Assuming that the cars have 5-foot trucks, the resistance in pounds per ton for cars, tender, and engine truck in the 5-degree curve is 2.325 pounds, and for the engine drivers 3.55 pounds. The total curve resistance on the three grades, the resistance per ton per degree, and the equivalent grade reduction, are, therefore: —

Grade — per cent	0.5	1.0	2.0
Curve resistance — total	4346.6	2574.9	1435.7
Per ton per degree — pounds	0.467	0.477	0.485
Equivalent grade reduction — per cent	0.0233	0.0238 +	0.0242 +

Contrary to certain published observations, the compensation is greater as the ruling grade is greater, due to the greater proportion of weight on the longer wheel base, but the difference is so slight it may be neglected. A locomotive with longer wheel base and no greater hauling capacity would indicate a greater reduction than that given. But it is thought that on good track, curve compensation of 0.025 per cent per degree will be found sufficient for 5-degree curves. The compensation, however, should vary with the degree of curve, and the following values are suggested: —

Degree of curve	1	2–4	5 and over
Grade compensation per degree	0.04	0.03	0.025

When there is no necessity to save in gradient, full compensation even up to 0.05 per cent per degree for all curves can do no harm.

With poor track, and badly curved rails, compensation should be high.

Virtual, or Velocity Grades. — If a locomotive by its own effort is increasing the speed of its train, it may be said that in effect it is overcoming the train resistance of a level track, the grade resistance of whatever grade it may be on, and that of a grade equivalent in effect to the acceleration resistance. It is then exerting the total effort required for a grade equal to the actual grade plus the grade of acceleration. Such a grade is called the virtual grade, because the locomotive is said to be virtually doing the work corresponding to uniform speed on such a grade.

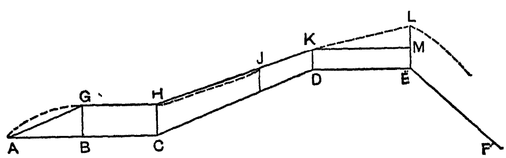


Fig. 79

Let a track have a profile ABCDEF, Fig. 79, and let a train be started from rest at A and expected to make a speed S by the

time B is reached. If the acceleration be uniform, and due to a uniform pull, the virtual grade of acceleration will be AG, such that its resistance equals that due to the acceleration. The train has not been lifted above the actual profile by BG, but the work necessary to do this has been done, in increasing the speed, in addition to the work necessary to draw the train against "train resistance." The distance BG therefore is the height through which a body must fall to gain the speed of *S* miles an hour, or it is the velocity head for that speed. The rate of the virtual grade, then, is the velocity head for the required increase in speed, divided by the distance in which the increase is had. The rate is in feet per hundred or per cent if the distance is expressed in stations of 100 feet. The actual virtual grade will not be a straight line if the locomotive is worked to its utmost throughout the distance AB, because the train resistance varying leaves a variable force available for acceleration. The actual virtual grade will be something like the dotted line, and could be drawn approximately by determining the virtual grade for successive increases of some small unit, say, 1 mile per hour, and the distances required for these increases.

If the speed at B be the utmost the locomotive can maintain on a level, or if it be the highest deemed safe, — about 30 miles for freight trains, — the motion from B to C will be uniform, there will be no grade due to acceleration, and the virtual grade will be level, equal to that of the track, and may be represented by GH. When C is reached, the speed will at once diminish. If the speed from B to C has been the utmost the locomotive could maintain on a level, the speed will diminish, the locomotive still exerting its maximum pull, until that speed that can be maintained on the grade CB is reached. As the effort available increases as the speed lessens, the virtual grade from H to J will not be the straight line but the dotted line.

If the speed from B to C is not the utmost that can be reached, the locomotive effort may be increased at C, the virtual grade HJ will be steeper than that shown, and JK may be higher above CD than indicated. When E is reached, if the speed is

the utmost wise, the virtual grade must descend parallel to EF, the locomotive doing the grade work corresponding to the difference between EF and the grade of repose for the operated speed. This may be nothing, when the steam will be shut off, the train descending under the influence of gravity, something (a positive quantity), when the locomotive will exert a pull, or less than anything (a negative quantity), when brakes must be used. If the speed at E is not the utmost wise or possible, the speed will increase from E, the virtual grade departing from EF at a rate depending on the effort of the locomotive, until the speed reaches the safe limit or utmost locomotive capacity, when it will continue parallel to EF.

The grade from L on to the next change may or may not, therefore, represent the grade virtually worked by the locomotive. Virtual profile is therefore not a good name for these grades. Velocity profile is more applicable, because if a profile be constructed as has just been described, it will at every point lie above the track profile by the velocity head for the speed at the point. For an increasing speed the two profiles will depart; for a uniform speed they will be parallel; for a decreasing speed they will approach; for a stop they will coincide. It is the velocity profile that must be studied in connection with locomotive work; and it is the velocity profile that must be considered in the design of grades, for a track grade may be virtually steeper or less steep than its nominal rate. For a single grade that does represent the work of the locomotive, virtual grade is a proper term.

In every case the rate of the velocity grade for a given change in speed, if the rate of change be considered uniform, is the difference in velocity head at the two limits of speed, divided by the distance used in the change. A table of velocity heads is therefore frequently useful in solving problems, and such a table is given on page 186.

To construct a velocity profile for an operated road, determine the speed at as many points as necessary, and at these points on the actual profile lay off vertically upward the velocity heads for the noted speeds. Connect the tops of these verticals for the

TABLE 2

VELOCITY HEADS IN FEET FOR SPEED IN MILES PER HOUR

Formula: $h = 0.035s^2$

Speed	.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03
1	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13
2	0.14	0.15	0.17	0.19	0.20	0.22	0.24	0.26	0.27	0.29
3	0.31	0.34	0.36	0.38	0.40	0.43	0.45	0.48	0.51	0.53
4	0.56	0.59	0.62	0.65	0.68	0.71	0.74	0.77	0.81	0.84
5	0.87	0.91	0.95	0.98	1.02	1.06	1.10	1.14	1.18	1.22
6	1.26	1.30	1.35	1.39	1.43	1.48	1.52	1.57	1.62	1.67
7	1.72	1.76	1.81	1.87	1.92	1.97	2.02	2.08	2.13	2.18
8	2.24	2.30	2.35	2.41	2.47	2.53	2.59	2.65	2.71	2.77
9	2.84	2.90	2.96	3.03	3.09	3.16	3.23	3.29	3.36	2.43
10	3.50	3.57	3.64	3.71	3.79	3.86	3.93	4.01	4.08	4.16
11	4.24	4.31	4.39	4.47	4.55	4.63	4.71	4.79	4.87	4.96
12	5.04	5.12	5.21	5.29	5.38	5.47	5.56	5.65	5.73	5.82
13	5.91	6.01	6.10	6.19	6.28	6.38	6.47	6.57	6.66	6.76
14	6.86	6.96	7.06	7.16	7.26	7.36	7.46	7.56	7.67	7.77
15	7.87	7.98	8.09	8.19	8.30	8.41	8.52	8.63	8.74	8.85
16	8.96	9.07	9.18	9.30	9.41	9.53	9.64	9.76	9.88	10.00
17	10.11	10.23	10.35	10.47	10.60	10.72	10.84	10.97	11.09	11.21
18	11.34	11.47	11.59	11.72	11.85	11.98	12.11	12.24	12.37	12.50
19	12.64	12.77	12.90	13.04	13.17	13.31	13.45	13.58	13.72	13.86
20	14.00	14.14	14.28	14.42	14.57	14.71	14.85	15.00	15.14	15.29
21	15.44	15.58	15.73	15.88	16.03	16.18	16.33	16.48	16.63	16.79
22	16.94	17.10	17.25	17.41	17.56	17.72	17.88	18.03	18.19	18.35
23	18.52	18.68	18.84	19.00	19.17	19.33	19.50	19.66	19.82	19.99
24	20.16	20.33	20.50	20.67	20.84	21.01	21.18	21.35	21.53	21.70
25	21.88	22.05	22.22	22.40	22.58	22.76	22.94	23.12	23.30	23.48
26	23.66	23.84	24.03	24.21	24.40	24.58	24.77	24.95	25.14	25.33
27	25.52	25.70	25.90	26.09	26.28	26.47	26.66	26.86	27.05	27.25
28	27.44	27.64	27.83	28.03	28.23	28.43	28.63	28.83	29.03	29.23
29	29.44	29.64	29.84	30.05	30.25	30.46	30.67	30.88	31.08	31.29
30	31.50	31.71	31.92	32.13	32.35	32.56	32.78	32.98	33.20	33.42
31	33.64	33.85	34.07	34.29	34.51	34.73	34.96	35.18	35.40	35.62
32	35.84	36.06	36.29	36.52	36.74	36.97	37.19	37.42	37.65	37.88
33	38.11	38.34	38.58	38.81	39.05	39.27	39.51	39.75	39.98	40.22
34	40.46	40.70	40.94	41.18	41.42	41.66	41.90	42.14	42.38	42.63
35	42.87	43.12	43.37	43.61	43.86	44.11	44.36	44.61	44.86	45.11
36	45.36	45.61	45.87	46.12	46.38	46.63	46.88	47.14	47.40	47.66
37	47.91	48.18	48.43	48.70	48.96	49.22	49.48	49.74	50.01	50.28
38	50.54	50.81	51.08	51.34	51.61	51.88	52.16	52.42	52.69	52.96
39	53.24	53.51	53.78	54.06	54.34	54.61	54.89	55.17	55.44	55.72
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
40	56.00	58.84	61.74	64.72	67.76	70.88	74.06	77.32	80.64	84.03
50	87.50	91.03	94.64	98.31	102.06	105.77	109.75	113.72	117.74	121.83
60	126.00	130.23	134.54	138.92	143.36	147.87	152.45	157.11	161.84	166.63
70	171.50	176.45	181.44	186.52	191.65	196.88	202.16	207.52	212.94	218.42
80	224.00	229.60	235.33	241.10	246.95	257.88	258.84	264.91	271.04	277.22
90	283.50	289.82	296.23	302.70	309.25	315.86	322.55	329.31	336.15	343.05
100	350.00									

Note: — For the table the theoretical heads have been increased 4.63 per cent to allow for the energy of the rotating wheels.

velocity profile. A study of such a profile indicates when the locomotive is overloaded or underloaded, and reveals the points at which changes in gradients may be made most economically. This study will be considered in another chapter. The velocity head is determined by substituting $\frac{5280\ S}{3600}$ for v in the acceleration formula, $h = \frac{v^2}{2g}$. An allowance of $4\frac{63}{100}$ per cent has been made in computing the table to provide for the independent rotation of the wheels.

The velocity profile for a projected road whose grade profile is known may be made by assuming speeds that must or may be had at certain points sufficiently close together, computing the velocities that may be had at intermediate points with an assumed train and locomotive, and connecting the tops of the corresponding velocity head ordinates erected at these points. For a problem of this kind see page 218, and for the fundamental problems involved see Chapter XIII.

Grade of Repose. — Grade of repose is a term that has been used in this discussion. It is a misnomer for it is not a grade of repose at all. What is so called varies with the velocity just as train resistance does, and for a given velocity is that grade the force of gravity down which just equals train resistance for the velocity considered. A train moving at a given velocity without locomotive effort, on its grade of repose for that velocity, will neither gain nor lose speed.

CHAPTER XIII

LOCOMOTIVE AND GRADE PROBLEMS

1. To find the Tractive Effort of a Given Locomotive. — Let a ten-wheel locomotive be considered, with principal dimensions required in these problems, as follows: —

Weight on drivers...............	131,200 pounds
Total engine and tender.........	304,000 pounds = 152 tons
Heating surface.................	2586.8 square feet
Working pressure................	185 pounds
Cylinders	22 inches diameter × 26 inches stroke
Diameter of drivers	63 inches

From Equation 1, page 140, tractive effort of adhesion is $T_a = fW = \frac{1}{4} \times 131{,}200$ for summer, and $\frac{1}{5} \times 131{,}200$ for winter, or $T_a \doteq 32{,}800$ pounds to 26,240 pounds.

Ultimate cylinder tractive effort is

$$T_c = \frac{Pd^2l}{D} = \frac{185 \times 0.85 \times \overline{22}^2 \times 26}{63} = 31{,}410 \text{ pounds.}$$

Boiler tractive effort is

$$T_b = \frac{146\,H}{S} = \frac{146 \times 2586.8}{S},$$

and varying with speed must be tabulated* for several speeds. No values are given for speeds below 12 miles an hour, since at that speed the cylinder tractive effort rather than the boiler effort will be the limiting factor. Indeed, it is doubtful if the cylinders can exert their ultimate effort at 12 miles an hour.

* The student may diagram the formula on axes of T_b and S, locating points for speeds varying by 5 miles and connecting these points by a curve which should give results essentially like those of the table. The working curve would be a straight line parallel to the axis of S for speeds between 0+ miles and 12 miles an hour, because the effort is then limited by the cylinders or adhesion and the boiler power curve does not apply.

TABLE 3

BOILER TRACTIVE EFFORT OF TEN-WHEEL LOCOMOTIVE OF PROBLEM 1, FOR SPEEDS FROM 10 TO 39.5 MILES.

(Nearest 10 pounds.)

$$\text{Equation } T_b = \frac{146 \times \text{Heating Surface in square feet}}{\text{Speed in miles per hour}}.$$

Speed—Miles per Hour	10	20	30
0.0		18,880	12,590
0.5		18,420	12,380
1.0	31,470	17,980	12,180
1.5		17,560	11,990
2.0		17,170	11,800
2.5	30,210	16,790	11,620
3.0	29,050	16,420	11,440
3.5	27,980	16,070	11,270
4.0	26,980	15,740	11,110
4.5	26,050	15,410	10,950
5.0	25,180	15,110	10,790
5.5	24,370	14,810	10,640
6.0	23,600	14,530	10,490
6.5	22,890	14,250	10,350
7.0	22,220	13,990	10,210
7.5	21,580	13,730	10,070
8.0	20,980	13,490	9,940
8.5	20,410	13,250	9,810
9.0	19,880	13,020	9,680
9.5	19,370	12,800	9,560

It may perhaps be considered that in summer, with fair track, this locomotive has a tractive effort of 32,000 pounds at speeds under 5 miles an hour, 31,400 pounds for speeds between 5 miles and 12 miles, and in accordance with the boiler tractive power table for higher speeds. It is very probable that the tractive effort may vary somewhat from the table in practice, for the engine will most likely follow the tabular values closely through some range of speed for which it is designed to give its best service, but outside of this range it may not equal the values given. It is more likely to give less values than the table for the higher

speeds. In subsequent problems the tractive effort of the locomotive will be assumed to be 31,400 pounds for speeds under 12 miles an hour, and as in this table for greater speeds.

2. To find the Maximum Load the Locomotive can haul on a Given Grade at a Given Speed. — Let the grade be 1 per cent, the speed 12 miles or under, the grade being considered the ruling grade.

Train resistance for a fully loaded train at 12 miles is approximately (Table 1)	4.4 pounds per ton
Grade resistance for a 1 per cent grade is	20.0 pounds per ton
Total resistance	24.4 pounds per ton

The tractive effort is 31,400 pounds

therefore

$$\text{Gross load} = \frac{31{,}400}{24.4} = \quad 1{,}287 \text{ tons}$$

Less the weight of the locomotive	152 tons
Net load behind tender	1,135 tons.

For safety in winter the gross load should be reduced, perhaps, one sixth or 215 tons, leaving the winter net load 920 tons. The number of cars represented will depend on the character of the traffic. Allowing about 90,000 pounds for each car and its load, the train will consist of about twenty-five cars and the caboose in summer, and, say, twenty cars in winter. In loading locomotives it is customary to use the loaded train resistance formula and to make an allowance for empty cars or cars partly loaded. The practice varies, but it is suggested that as nearly as may be three empty cars may be considered equivalent to two fully loaded cars. Another rule which will give closely approximate results is this:—

Add $1\frac{1}{2}$ times the dead load (cars) and $\frac{3}{4}$ of the live load (freight) for an equivalent weight of fully loaded cars. This rule may be used when a system of tonnage rating of locomotives is practiced.

The great value of the fullest possible loading will appear from a consideration of the meaning of this rule.

If W be the weight of cars, L the weight of load, and K the net load of fully loaded cars a locomotive can handle on a level,

$$1.5\,W + 0.75\,L = K.$$

L may vary from nothing to about 2 W as a maximum.

For $W = 2\,L$, or a quarter load, $L = 0.267\,K$
For $W = L$, or a half load, $L = 0.444\,K$
For $W = \frac{1}{2}L$, or a full load, $L = 0.667\,K$.

Or, the paying load in a train of fully loaded cars is $2\frac{1}{2}$ times that in quarter loaded cars, and $1\frac{1}{2}$ times that of half loaded cars.

Owing to the bulkiness of some classes of freight not all cars can be loaded to their weight capacities, and some freight must be moved quickly, but attention to this matter is of great importance. An increase of 25 per cent in the loading of half loaded trains would decrease the maximum train mileage 13 per cent, or a probable reduction equivalent to $2\frac{1}{2}$ per cent of the total operating expenses, or about $15,000 a year per 100 miles of average Mississippi Valley railroad.

Since it is only train resistance that is not alike for dead and live load, problem 2 will be solved for a partly loaded train. Considering the locomotive as a fully loaded car of weight E tons, the total resistance placed equal to the tractive effort will give

$$(1.5\,W + 0.75\,L + E)\,R_t + (W + L + E)\,R_g = T.$$

If a given number and weight of cars is to be carried and it is desired to know how much live load may be added, the foregoing equation is solved for L. But if L is expressed in terms of W, as $L = W$, a half load, $L = 2\,W$, a whole load, W may be found, then L, giving the required result, $W + L$. Thus, let $L = W$, and the other quantities be as in Problem 2, then

$$(2.25\,W + 152)\,4.4 + (2\,W + 152)\,20 = 31{,}400$$
$$W = 555 - \text{tons}$$
$$W + L = 1110 - \text{tons}.$$

The total load is 1110 tons against 1135 tons of fully loaded train and the paying loa ; but 555 tons against 756 tons.

3. To find the ade up which Two Similar Locomotives can haul the Loa . that One can haul on a Given Grade.—This is the problem of the pusher or helper grade.

Let the locomotives be as in the last problem, the through engine loaded with 1135 tons behind the tender, 1287 tons gross, corresponding to a 1 per cent grade. The load on the pusher grade is $1287 + 152 = 1439$ tons, the total tractive effort twice that of one locomotive less a small per cent, — say, 10 per cent, — due to failure of both locomotives to work together, or 56,520 pounds. Grade resistance plus train resistance must equal the tractive effort.

If x be the rate of grade sought

$$(20\,x + 4.4)\ 1439 = 56{,}520$$
$$x = 1.75 \text{ per cent.}$$

If the helping locomotive is of less capacity, the helper grade will be correspondingly less, and, conversely, if the grade be less than 1.75 per cent, a lighter locomotive than the through locomotive may be used.

4. To find the Speed that can be Maintained on a Grade Less than that for which a Locomotive is Loaded. — The locomotive already considered, loaded for 12 miles or less on a 1 per cent grade, carries a gross load of 1287 tons. What speed can be maintained on a $\frac{5}{10}$ per cent grade?

The grade resistance is 10 pounds per ton, the train resistance as in Equation 1, page 162, the tractive effort, $\dfrac{146 \times 2586.8}{S}\cdot$ Even omitting the third term of the train resistance equation, the solution for S leads to a cubic equation, and the determination is best made by inspection. The tractive effort in pounds per ton of maximum load at the various speeds is tabulated, train resistance in pounds per ton is taken from the curve of train resistance for various speeds, or from tabulated values, page 163, and that speed selected which with 10 pounds for grade resistance gives a resist-

ance equal to the tractive effort per ton. Thus, from the table it is seen that a speed of about 18.9 miles can be maintained on a 0.5 per cent grade with a load that can be hauled at 12 miles on a 1 per cent grade.

TABLE 4

Tractive effort in pounds per ton of a ten-wheel locomotive with dimensions given below, when loaded with 1287 tons gross load, which can be hauled at 12 miles an hour on a 1 per cent grade.

Weight on drivers, 131,200 pounds. Heating surface, 2586.8 square feet. Cylinder, 22 inches × 26 inches. Total engine and tender, 304,000 pounds. Working pressure, 185 pounds. Diameter of drivers, 63 inches.

Formulas: above 12 miles an hour, $T_b = \dfrac{146 \times H}{S} = \dfrac{146 \times 2586.8}{S}$.

Tractive effort in pounds per ton of maximum load $= \dfrac{T_b}{\text{max. load}} = \dfrac{T_b}{1287}$.

Speed—Miles per Hour	10	20	30
0.0		14.67	9.78
0.5		14.32	9.62
1.0	24.40	13.97	9.47
1.5		13.65	9.32
2.0		13.34	9.17
2.5	23.48	13.04	9.03
3.0	22.58	12.76	8.89
3.5	21.74	12.49	8.76
4.0	20.96	12.23	8.63
4.5	20.24	11.98	8.51
5.0	19.57	11.74	8.38
5.5	18.93	11.51	8.27
6.0	18.34	11.29	8.15
6.5	17.89	11.07	8.04
7.0	17.27	10.87	7.93
7.5	16.77	10.67	7.83
8.0	16.30	10.48	7.72
8.5	15.76	10.30	7.62
9.0	15.45	10.12	7.52
9.5	15.05	9.95	7.43

A table useful for other problems as well may be made, showing the net tractive force in pounds per ton available on a level

grade for acceleration or grade climbing, and the corresponding virtual grade. In such a table the grade corresponding to the required speed will be sought. To make such a table, the total tractive effort in pounds per ton (Table 4) is diminished by the train resistance in pounds per ton, giving the net tractive force in pounds per ton available for acceleration or grade climbing, and this quantity divided by 20 gives the corresponding virtual grade,—that is, the grade that can be operated at the given speed. Table 5 is such a table for the locomotive of the problem. Inspection shows the speed corresponding to 0.5 per cent to be about 18.9 miles as before.

TABLE 5

Tractive force in pounds per ton of load hauled at 12 miles an hour on a 1 per cent grade, available for acceleration or grade climbing and the corresponding virtual grade per cent. Locomotive is ten-wheel of dimensions given on page 188. Tractive effort in pounds per ton from Table 4; R_t, from Table 1, page 163.

Formulas: Tractive force available (first tabular quantity) $= \frac{T}{W} - R_t$.

$$\text{Virtual grade} = \frac{\text{First tabular quantity}}{20} = \text{Second tabular quantity.}$$

Speed—Miles per Hour	0 Force	0 Grade	10 Force	10 Grade	20 Force	20 Grade	30 Force	30 Grade
0.0	5.40	0.2700	20.22	1.0110	8.94	0.4470	1.31	0.0655
0.5	13.79	0.6895	20.17	1.0085	8.48	0.4240	0.98	0.0490
1.0	16.90	0.8450	20.13	1.0065	8.02	0.4010	0.66	0.0330
1.5	18.33	0.9167	20.07	1.0035	7.58	0.3790	0.34	0.0170
2.0	19.10	0.9550	20.00	1.0000	7.15	0.3575	0.02	0.0010
2.5	19.56	0.9780	19.03	0.9515	6.73	0.3365	−0.30	−0.0150
3.0	19.85	0.9925	18.08	0.9040	6.32	0.3160	−0.61	−0.0305
3.5	20.05	1.0025	17.16	0.8580	5.92	0.2960	−0.92	−0.0460
4.0	20.17	1.0085	16.32	0.8160	5.53	0.2765	−1.24	−0.0620
4.5	20.26	1.0130	15.51	0.7755	5.16	0.2580	−1.55	−0.0775
5.0	20.32	1.0160	14.77	0.7385	4.78	0.2390	−1.87	−0.0935
5.5	20.35	1.0175	14.05	0.7025	4.41	0.2205	−2.17	−0.1085
6.0	20.38	1.0190	13.38	0.6690	4.06	0.2030	−2.49	−0.1245
6.5	20.39	1.0195	12.84	0.6420	3.69	0.1845	−2.80	−0.1400
7.0	20.38	1.0190	12.13	0.6065	3.34	0.1670	−3.11	−0.1555
7.5	20.37	1.0185	11.54	0.5770	2.99	0.1495	−3.41	−0.1705
8.0	20.35	1.0175	10.98	0.5490	2.75	0.1375	−3.73	−0.1865
8.5	20.32	1.0160	10.34	0.5170	2.31	0.1155	−4.04	−0.2020
9.0	20.30	1.0150	9.93	0.4965	1.97	0.0985	−4.35	−0.2175
9.5	20.25	1.0125	9.42	0.4710	1.64	0.0820	−4.66	−0.2330

At 32 miles an hour there is a practical balance of tractive effort and resistance. Greater speeds can be maintained only on descending grades of the rates given up to 39.5 miles.

5. To find the Distance required to increase the Speed a Given Amount on a Given Grade. — Let the elements of the foregoing problems be used. Let a train leave a 1 per cent grade traveled at 12 miles and enter a 0.5 per cent grade of indefinite length, what distance will be required to reach a speed of 18 miles an hour? The acceleration will not be uniform because the force available for acceleration will be constantly decreasing as the speed increases. The train does not enter the grade all at once. The problem is incapable of exact solution except by a tedious series of approximations. Several approximate methods will be given, all of which have been used, to show the relation of the results.

(*a*) The forces available for acceleration at the high speed and low speed are averaged, the acceleration is assumed to be uniform and due to this force, which is then substituted in Equation (B), page 168.

(*b*) The solution is the same except that the accelerating force is that available at the average speed.

(*c*) Uniform acceleration is assumed to prevail during the increase of speed from n miles to $n + 1$ miles an hour, the accelerating force to be that available at the lower speed, or the higher speed, or at a mean of the two speeds (the last is the most nearly correct) and solution is made as in (*a*) and (*b*).

(*a*) and (*b*). The available force in pounds per ton at 12 miles is

$$24.4 - (4.4 + 10) = 10 \text{ pounds};$$

at 18 miles

$$16.30 - (5.31 + 10) = 1 - \text{pound}.$$

The average force, therefore, is 5.5 pounds.

At the average speed of 15 miles an hour the available force is

$$19.57 - (4.80 + 10) = 4.77 \text{ pounds}.$$

In Equation (B), when W is 1, P is the force in pounds per ton, and

$$l = \frac{70}{5.5 \text{ or } 4.77}(18^2 - 12^2) = 2291 \text{ or } 2641 \text{ feet.}$$

The very considerable error of both these results will be seen from the solution by the third method.

(*c*) Using Equation (E) and the force available near the higher, lower, and average speeds, respectively,

$$l(12\text{-}13) = \frac{70\ (24 + 1)}{8.08 \text{ or } 10 \text{ or } 9.03} = 217 \text{ or } 175 \text{ or } 194$$

$$l(13\text{-}14) = \frac{70\ (26 + 1)}{6.32 \text{ or } 8.08 \text{ or } 7.16} = 299 \text{ or } 234 \text{ or } 264$$

$$l(14\text{-}15) = \frac{70\ (28 + 1)}{4.77 \text{ or } 6.32 \text{ or } 5.51} = 426 \text{ or } 321 \text{ or } 368$$

$$l(15\text{-}16) = \frac{70\ (30 + 1)}{3.38 \text{ or } 4.77 \text{ or } 4.05} = 642 \text{ or } 455 \text{ or } 536$$

$$l(16\text{-}17) = \frac{70\ (32 + 1)}{2.13 \text{ or } 3.38 \text{ or } 2.84} = 1084 \text{ or } 683 \text{ or } 813$$

$$l(17\text{-}18) = \frac{70\ (34 + 1)}{0.98 \text{ or } 2.13 \text{ or } 1.54} = 2500 \text{ or } 1150 \text{ or } 1591$$

$$\overline{l(12\text{-}18)} \qquad \overline{5168 \text{ or } 3018 \text{ or } 3766}$$

The truth lies somewhere between the first and last results. The wide discrepancy in this case is due to the fact that the higher speed is about the limit possible for the lower grade. If anything like very close results are required, the differences in speed should be by tenths of miles for such cases. When the upper speed does not approach the limit of locomotive capacity, the

results are close enough, if differences of single miles are used. The assumption that the locomotive is doing its theoretical utmost at any instant is somewhat wide of the truth, because the engine driver cannot so handle the throttle and cut-off as to maintain a constant power output; hence very close estimates are impossible. Such problems occur in planning grades for a new line. On an operated line, the actual performance of the locomotive may be known.

(*d*) A method of solution by the use of tables already computed will be given. The P of Equation (B), page 168, is the tractive effort available for acceleration, and this in pounds per ton of load is $\frac{T}{W} - R_t - R_g$, T being total tractive effort in pounds; hence Equation (B) becomes, if r be the per cent of the grade operated,

$$l = \frac{70\,(S_2^{\,2} - S_1^{\,2})}{\left(\frac{T}{W} - R_t\right) - 20\,r}.$$

If both numerator and denominator be divided by 20,

$$l = \frac{3.5\ (S_2^{\,2} - S_1^{\,2})}{\frac{1}{20}\left(\frac{T}{W} - R_t\right) - r}. \qquad \text{(M)}$$

The numerator of this fraction is one hundred times the difference in velocity heads, and the parenthetical term of the denominator is the virtual grade for the speed corresponding to T and R_t. If v represent this grade, then

$$l = \frac{100 \times \text{difference in velocity heads}}{v - r}$$

or, in stations of one hundred feet

$$l \text{ stations} = \frac{\text{difference in velocity heads}}{v - r}.$$

From the table of velocity heads, page 186, and that for virtual grades, page 194, using the virtual grades of the average speeds,

$$l\,(12\text{-}13) = \frac{5.915 - 5.040}{0.9515 - 0.5} = 1.94$$

$$l\,(13\text{-}14) = \frac{6.86 - 5.915}{0.858 - 0.5} = 2.64$$

$$l\,(14\text{-}15) = \frac{7.875 - 6.86}{0.7755 - 0.5} = 3.68$$

$$l\,(15\text{-}16) = \frac{8.96 - 7.875}{0.7025 - 0.5} = 5.36$$

$$l\,(16\text{-}17) = \frac{10.115 - 8.96}{0.642 - 0.5} = 8.13$$

$$l\,(17\text{-}18) = \frac{11.34 - 10.115}{0.577 - 0.5} = 15.91$$

$$l\,(12\text{-}18) \text{ in stations of 100 feet} = 37.66$$

There is perhaps not much gained over the previous method, which is of course exactly the same except in arrangement. The numbers in the tabular method involve more digits, but there are fewer operations.

6. To find the Length of Grade required to reduce the Speed from S_1 Miles to S_2 Miles an Hour. — Let the locomotive and load be as in the previous problems. Let the speed of approach be 20 miles, the final speed, 10 miles an hour, and the rate of grade, 1.5 per cent.

This is precisely the previous problem, in which both numerator and denominator of Equation (B) are negative. The grade resistance is now 30 pounds per ton. The train resistance varies from 5.73 pounds at 20 miles to 4.18 pounds at 10 miles. Solving by Equation (E) page 168, for successive reductions of 1 mile an hour, and using the average speed for T and R_t,

$$l = \frac{-70\,(2\,S_1 - 1)}{\frac{T}{W} - R_t - R_g}.$$

The numerator is the same numerically as before, as it should be, being 2000 times the difference in velocity head for two speeds differing by one mile.

$$l\,(20\text{-}19) = \frac{-70\,(39)}{15.05 - 5.63 - 30} = 133 \text{ feet}$$

$$l\,(19\text{-}18) = \frac{-70\,(37)}{15.76 - 5.42 - 30} = 132 \text{ feet}$$

$$l\,(18\text{-}17) = \frac{-70\,(35)}{16.77 - 5.23 - 30} = 133 \text{ feet}$$

$$l\,(17\text{-}16) = \frac{-70\,(33)}{17.89 - 5.05 - 30} = 135 \text{ feet}$$

$$l\,(16\text{-}15) = \frac{-70\,(31)}{18.93 - 4.88 - 30} = 136 \text{ feet}$$

$$l\,(15\text{-}14) = \frac{-70\,(29)}{20.24 - 4.73 - 30} = 140 \text{ feet}$$

$$l\,(14\text{-}13) = \frac{-70\,(27)}{21.74 - 4.58 - 30} = 147 \text{ feet}$$

$$l\,(13\text{-}12) = \frac{-70\,(25)}{23.48 - 4.45 - 30} = 160 \text{ feet}$$

$$l\,(12\text{-}11) = \frac{-70\,(23)}{24.40 - 4.33 - 30} = 162 \text{ feet}$$

$$l\,(11\text{-}10) = \frac{-70\,(21)}{24.40 - 4.23 - 30} = 150 \text{ feet}$$

$$\overline{l\,(20\text{-}10)} \qquad = \overline{1428} \text{ feet}$$

The small difference in the several partial distances suggests that a sufficiently close result might have been obtained by using the initial and final speeds with a tractive effort and train resistance due to the average speed, or straight line averages of the

tractive efforts and train resistances for the final and initial speeds. The results by these methods are: —

$$l = \frac{70\ (100 - 400)}{19.57 - 4.80 - 30} = 1379$$

$$l = \frac{70\ (100 - 400)}{19.535 - 4.945 - 30} = 1362.$$

Either result is perhaps sufficiently close for practical problems, and both are on the safe side, since the danger in this problem is in overestimating the length of the grade. The problem is the momentum or velocity grade problem in which it is desired to find how long a grade steeper than the ruling grade may be introduced in the profile without reducing the maximum load. This problem indicates that for this particular locomotive and loading about 1400 feet of 1.5 per cent grade may be introduced if circumstances seem to warrant it, without reducing the load for a 1 per cent ruling grade, provided a speed of 20 miles may always be had at the foot of the grade. This will depend on the character of the preceding gradients and the alignment, and this question must be thoroughly studied before introducing such a grade.

If the excessive grade differs but little from the ruling grade, the same difficulty in securing a definite result that appeared in Problem 5 will be found, and a long grade will result; but great precision is not then required, since it is doubtful if gravity and the locomotive can be made to work together so well as to insure spreading the velocity head out over a very long stretch. Just what length of grade may be safely operated as a velocity grade will depend on the rate of it, and the velocity of approach and leaving. It cannot be mathematically determined. It is suggested that it is doubtful wisdom to introduce such grades of more than 2000 feet unless there is a good surplus of velocity head to be used up, and that if a longer grade than this seems desirable, not less than 12 or 15 miles an hour should be assumed at the top in computing. It is said that grades of 2 miles have been successfully operated as velocity grades.

The solution of the reverse of this problem — that is, to find the resulting speed at the end of a given stretch of steep grade — will be clear.

7. To find the Time required to increase or decrease Speed from One Rate to Another in a Given Distance. — The time required to gain the velocity v feet per second from rest, if gained in the distance l feet is

$$t = l \div \frac{v}{2}$$

with v expressed in miles per hour S, since

$$v = \frac{5280}{3600} S$$

$$t = \frac{15}{11} \frac{l}{S},$$

and if the speed is to be increased from S_1 to S_2 miles per hour in the distance l feet, the time required is

$$t \text{ seconds} = \frac{15}{11} \cdot \frac{l}{S_1 + S_2}. \qquad \text{(R)}$$

Hence, having found the distance required for a given acceleration or retardation, substitute it for l in Equation (R) and solve for the time.

Let the data of Problem 6 be used.

$$S_1 + S_2 = 30$$
$$l = 1428$$

and $$t = \frac{15 \times 1428}{11 \times 30} = 65 - \text{seconds.}$$

This assumes the acceleration to be uniform for the given distance, which — though not true — gives a sufficiently close result for practical use. If the time required for each successive reduction of 1 mile be computed and the results added, the total time

is 68.8 seconds, and it may be that the actual time required is about 70 seconds.

Let the data of Problem 5 be used.

$$S_1+S_2 = 30$$
$$l = 3766$$

and $$t = \frac{15}{11} = \frac{3766}{30} = 171 \text{ seconds.}$$

As before, if the time for each successive change of 1 mile be used, $t = 117.62$ seconds. The discrepancy indicates again that when the grade is close to the limiting grade for the final speed, the results by approximate formulas are unreliable. The limiting grade for 18 miles an hour is close to a 0.5 grade, since for 18.9 miles the grade is 0.5 per cent.

8. Stopping a Train.—A train may be stopped by the resistance of an adverse grade, but it is usually stopped by the action of brakes applied to the wheels, helped by an adverse grade or hindered by a down grade. That which actually stops the train is the resistance to sliding on the rails, just as it is this resistance that enables the locomotive to pull the train. The wheels have a rotating motion independent of the forward motion of the car, and this motion could be almost instantly stopped by a sudden application of sufficiently powerful brakes; but thus braking the wheels would not stop the forward motion of the car because the resistance to sliding on the track is not sufficiently great, the wheels would skid along the track. The coefficient of static friction between the wheel and rail may be $\frac{1}{4}$, but so soon as the wheels slip, this friction drops materially. To stop the train in the shortest practicable time, therefore, the brake action should be just sufficient to call into action the full coefficient of static friction, and no more. This cannot be realized without frequently exceeding the limit, skidding the wheels, and thus making the brake action less efficient, flattening the wheels, and wearing the track. Therefore, in designing the brakes, the pres-

sure and leverage are so arranged that there shall ordinarily be an ample safety factor against skidding.

Air brakes are usually so designed that the brake pressure on any wheel shall not exceed 90 per cent of the empty car wheel-load for passenger cars, and 70 per cent of the empty car wheel-load for freight cars. The coefficient of friction, f, between brake shoes and wheels varies from perhaps 0.06 to 0.08 at high speeds, to possibly as high as 0.3 when the wheels are barely moving. It may be averaged at about $\frac{1}{6}$.

If a loaded freight car of weight W pounds be moving on a straight and level track at S miles an hour, its kinetic energy is its velocity head times its weight, or (including the rotation energy of the wheel) 0.035 S^2W. If the empty car weighs w pounds and brake pressure and friction be assumed to be constant throughout a stop, the retarding action of the brakes is 0.70 fw, and if l be the distance in which the stop is made,

$$0.70\, fw \times l + \frac{W}{2000} R_t l = 0.035\, S^2 W. \qquad (1)$$

If f be taken at $\frac{1}{6}$; S 20 miles an hour; train resistance R_t constant at an average of 4.6 pounds per ton; W 92,000; w 32,000; then,

$$l = \frac{0.035 \times 400 \times 92{,}000}{0.7 \times \frac{1}{6} \times 32{,}000 + 46 \times 4.6} = 326 \text{ feet.} \qquad (2)$$

The time required is

$$t = \frac{15}{11} \frac{l}{S} = \frac{15}{11} \frac{326}{20} = 22 + \text{seconds.} \qquad (3)$$

The actual conditions vary somewhat from those assumed, but the results are not wide of the facts, and are therefore instructive.*

* At present not all trains have all their wheels braked, the coefficient of friction is not constant, nor is the pressure applied, nor the train resistance; these elements vary in such a way as to increase the distance and reduce the time.

An ascending grade would assist the stop, its term being $20r\frac{W}{2000}l$. A descending grade would similarly retard the stop by the same quantity. If not all wheels are braked, only that portion of the dead weight that is braked could be used in the brake pressure term of the denominator of Equation (2).

9. To determine the Characteristics of a Locomotive adapted to a Given Division of Road. — The following is the general process: 1. The load to be hauled on the ruling grade at the minimum speed is assumed, and from the maximum tractive effort necessary to haul this load, the total weight on drivers is determined, and from this and the allowable unit weight, the number of drivers. It must be noted that the result is rational and practicable. 2. A desirable average schedule time is assumed. 3. Some grade on the division estimated to require the full capacity of the locomotive when running with maximum load at average speed is selected, and its resistance and train resistance at the average speed are used to determine the power required. 4. With this determined power and a profile of the division, a velocity profile for the assumed load is constructed, the resulting average schedule compared with that assumed, and the determined power is modified as may be desirable and increased for engine friction. 5. From the finally determined power the heating surface is computed from the equation I. H. P. $= 0.43\ H$, it being noted that the result is rational. The requirement then is a locomotive of the determined number of drivers, weight on drivers, cylinder horse-power to be developed most economically at the assumed average speed, maximum cylinder tractive effort equal to the tractive effort of adhesion at minimum speed, and boiler capacity sufficient to maintain such maximum speed as is necessary on the steepest grade on which it must be made.

A statement of these requirements may be submitted to the designer for a detail design.

CHAPTER XIV

RAILROAD EXPENDITURES

Fixed Charges. — Railroad expenditures are of two classes: 1. Fixed charges; 2. Operating expense. Fixed charges include interest on investment or capital, rentals and leases, and taxes, and constitute from 22 to 40 per cent of the total expenditure of operating roads, the average for the United States being about 27 per cent. Extreme and peculiar cases give wide variations from these figures. A road of unusual first cost and small business, or unusual capitalization, which may or may not represent cost, will have relatively high fixed charges. A road of small first cost or small capitalization and large business will have relatively low fixed charges. An operated road — a road leased by its owning company to an operating company — will have no operating expense to its owners, and fixed charges will be 100 per cent of the expenditures. The gross amount of fixed charges is so largely varied by regular and irregular methods of finance that little can be predicted for any given road. The average American road with its buildings and equipment may cost $35,000 a mile, which at 5 per cent would indicate an interest charge of $1750 per mile of road. Of the cost, about $30,000 may represent the cost of road and $5000 the cost of buildings and equipment. The funded debt of American roads is about $34,000 per mile of road.

Taxes are usually arbitrarily fixed, the different States pursuing different policies. The taxes per mile of line vary from about $100 in South Dakota to $1426 in Massachusetts. The average for the country is $301.

To be a profitable investment a railroad should earn its operating expense, including a sinking fund to perpetuate the entire property and provide for betterments, and a fair interest on the capital

actually invested in it. It is usually expected to pay, and so-called successful roads do pay, the items named, and a further return called dividends on what is known as the capital stock, which usually represents but little actually invested capital. There are some notable exceptions to this statement.

Operating Expense. — The unit for measuring operating expense in America is the train mile, — that is, one train run one mile. The passenger mile or the ton mile might seem more rational units, but they are too small and too variable. The cost of running a passenger train is about the same whether it be full of passengers or empty; and as the same schedule train runs full one day, partly full the next, full on the same trip between two stations and partly full between the next two, the actual passenger mile cost as a unit for estimates is of small value. The same thing is true of freight trains, perhaps in less degree.

The units of tariff, on the other hand, are the passenger mile and ton mile. In passenger service this unit is quite rigidly used, the rate from one point to another being figured from the number of miles and the rate per mile. But freight tariffs are largely independent of distance, and while usually stated at a definite rate per ton, or per 100 pounds, this rate is fixed by what the traffic will bear, which is only partially measured by the length of the haul, and it may be said generally that the longer the haul, the less per ton mile must be the rate.

The cost of operating a railroad depends on so many things that they cannot be enumerated. Three general items affecting this cost are: —

1. Management. 2. Country or district in which the road lies. 3. Skill shown in location.

Management is a matter of judgment, and includes selection of men, their care and discipline, adaptation of motive power and rolling stock to needs of traffic, care and maintenance of plant, fixing of rates, determining relations with the public, etc.

Territory in which the road lies includes the effect of topography (limiting grades and alignment), climate, cost of materials

and supplies of all kinds, character and cost of labor, and character and density of population and traffic.

The effect of location and construction will be considered in detail in subsequent pages. Subject to topographical limitations, the location determines the rate of the ruling grade, the character of the alignment, and arrangement of the minor grades of the profile, the highest skill finding alignment and ruling grade best adapted to the topography.

The ruling grade determines the number of trains to do a given service by limiting the weight of one train, and the alignment and arrangement of minor grades affect the cost per train.

The cost of moving one train one mile has been somewhat rapidly rising. From an average cost of about $1 (rather less) in 1894, it had risen to about $1.31 in 1904. The advance was not regular, and was most rapid in the last five years. The advance was due to three principal causes: 1. Higher wages. 2. Heavier and more luxurious trains. 3. Higher speeds.

The relative cost of freight train miles and passenger train miles has not been well determined, but the ratio is perhaps not far from 8 to 5, so that if all train miles average $1.31, freight train miles may average $1.60, and passenger train miles $1. This last is probably a high figure for ordinary local passenger trains, and $1.60 is a high figure for comparatively light, through freight trains. But some of the eastern trunk line high-speed through passenger trains may cost $2 a train mile, and very heavy through freight trains or lighter way trains that stop at every station to do some switching, may cost as much.

The Interstate Commerce Commission reports* operating expenses under fifty-three different heads, and publishes from year to year a tabulated statement of the percentage that each item is of the whole. Any percentage given in the table multiplied by the total average train-mile cost will give the cost per train mile for the single item. If the train-mile cost be assumed as

* "Statistics of Railways in the United States." Published annually by the Interstate Commerce Commission.

TABLE 6 *

CLASSIFICATION OF OPERATING EXPENSES FOR THE YEAR ENDING JUNE 30, 1904, AND PROPORTION OF EACH CLASS TO TOTAL FOR THE YEARS ENDING JUNE 30, 1904, TO 1900.

Item.	Amount.	Per cent.				
	1904.	1904.	1903.	1902.	1901.	1900.
Maintenance of way and structures:						
1. Repairs of roadway	$138,300,607	10.348	11.093	11.331	10.924	10.995
2. Renewals of rails	17,345,483	1.298	1.386	1.521	1.676	1.138
3. Renewals of ties	33,668,585	2.519	2.487	2.838	3.140	3.036
4. Repairs and renewals of bridges and culverts.	29,778,004	2.228	2.461	2.593	2.730	2.703
5. Repairs and renewals of fences, road crossings, signs, and cattle guards.	5,839,385	.437	.527	.625	.598	.616
6. Repairs and renewals of buildings and fixtures.	28,697,616	2.147	2.590	2.562	2.417	2.466
7. Repairs and renewals of docks and wharves.	2,789,094	.209	.235	.220	.283	.308
8. Repairs and renewals of telegraph.	2,385,300	.179	.165	.173	.158	.153
9. Stationery and printing	392,801	.029	.032	.031	.029	.030
10. Other expenses	1,669,816	.125	.209	.361	.317	.352
Total	$260,866,691	19.519	21.185	22.255	22.272	21.797
Maintenance of equipment:						
11. Superintendence	$7,572,965	.567	.559	.601	.599	.597
12. Repairs and renewals of locomotives.	105,633,752	7.904	7.408	7.246	6.695	6.730
13. Repairs and renewals of passenger cars.	26,078,106	1.951	2.044	2.157	2.277	2.263
14. Repairs and renewals of freight cars	103,932,132	7.777	7.442	7.432	7.436	7.687
15. Repairs and renewals of work cars	3,081,998	.231	.242	.245	.233	.252
16. Repairs and renewals of marine equipment.	2,065,442	.154	.177	.215	.234	.251
17. Repairs and renewals of shop machinery and tools.	9,411,076	.704	.696	.643	.605	.604
18. Stationery and printing	566,948	.042	.046	.044	.043	.043
19. Other expenses	8,515,198	.637	.519	.544	.507	.502
Total	$266,857,617	19.967	19.133	19.127	18.629	18.929

* From I. S. C. C. Statistical Report for 1904.

TABLE 6* — *Continued.*

Item.	Amount.	Per cent.				
	1904.	1904.	1903.	1902.	1901.	1900.
Conducting transportation:						
20. Superintendence	$23,533,951	1.761	1.742	1.711	1.726	1.831
21. Engine and round-house men	125,440,824	9.386	9.562	9.401	9.340	9.476
22. Fuel for locomotives	158,948,886	11.893	11.675	10.776	10.602	9.809
23. Water supply for locomotives	8,894,551	.666	.614	.623	.612	.599
24. Oil, tallow, and waste for locomotives.	5,460,629	.409	.389	.366	.361	.365
25. Other supplies for locomotives	3,351,739	.251	.232	.218	.206	.188
26. Train service	88,237,172	6.602	6.677	6.737	7.011	7.244
27. Train supplies and expenses	20,777,084	1.555	1.552	1.500	1.471	1.467
28. Switchmen, flagmen, and watchmen	57,909,962	4.333	4.313	3.984	3.848	3.944
29. Telegraph expenses	23,362,675	1.748	1.754	1.784	1.785	1.812
30. Station service	86,339,589	6.460	6.664	6.832	6.947	7.103
31. Station supplies	10,361,992	.775	.667	.676	.672	.679
32. Switching charges — balance	3,985,153	.298	.244	.272	.319	.340
33. Car per diem and mileage — balance.	20,340,343	1.522	1.400	1.480	1.618	1.800
34. Hire of equipment — balance	5,738,952	.429	.214	.180	.161	.223
35. Loss and damage	17,002,602	1.272	1.094	.990	.819	.764
36. Injuries to persons	15,838,179	1.185	1.120	1.048	.911	.910
37. Clearing wrecks	3,631,352	.272	.284	.221	.189	.173
38. Operating marine equipment	11,074,030	.829	.745	.721	.862	.866
39. Advertising	5,937,816	.444	.428	.429	.428	.432
40. Outside agencies	19,563,159	1.464	1.449	1.579	1.615	1.519
41. Commissions	822,212	.062	.044	.077	.089	.151
42. Stock yards and elevators	2,738,499	.205	.057	.069	.075	.060
43. Rents for tracks, yards, and terminals.	19,694,025	1.474	1.544	1.519	1.724	1.728
44. Rents of buildings and other property.	5,103,561	.382	.411	.440	.440	.464
45. Stationery and printing	8,557,541	.640	.642	.622	.638	.653
46. Other expenses	4,726,400	.353	.376	.416	.510	.579
Total	$757,372,878	56.670	55.893	54.671	54.979	55.179
General expenses:						
47. Salaries of general officers	11,234,945	.841	.823	.925	.984	1.041
48. Salaries of clerks and attendants	17,552,570	1.313	1.254	1.244	1.262	1.269
49. General office expenses and supplies.	3,080,718	.230	.234	.249	.257	.262
50. Insurance	6,289,915	.471	.432	.412	.384	.349
51. Law expenses	6,856,870	.513	.541	.558	.625	.571
52. Stationery and printing (general offices).	2,272,390	.170	.175	.168	.161	.166
53. Other expenses	4,091,731	.306	.330	.391	.447	.437
Total	$51,379,139	3.844	3.789	3.947	4.120	4.095
Recapitulation of expenses:						
54. Maintenance of way and structures.	260,866,691	19.519	21.185	22.255	22.272	21.797
55. Maintenance of equipment	266,857,617	19.967	19.133	19.127	18.629	18.929
56. Conducting transportation	757,372,878	56.670	55.893	54.671	54.979	55.179
57. General expenses	51,379,139	3.844	3.789	3.947	4.120	4.095
Grand total	$1,336,476,325	100.	100.	100.	100.	100.

$1, the tabular values are the costs of the several items in cents per train mile.

For any given road the figures will vary from those of the table, and will be in themselves variable from year to year. The Interstate Commerce Commission publishes also a statement for each interstate road in the country, showing the amounts of the four principal divisions of expense, and the cost per train mile. These figures are of value in preliminary estimates.

CHAPTER XV

EFFECT ON OPERATING EXPENSES OF CHANGE IN THE NUMBER OF TRAINS, THE TONNAGE REMAINING CONSTANT

The Problem. — Let it be supposed that a change in the ruling grade will be made, increasing or decreasing the maximum train load, and hence decreasing or increasing the number of maximum trains; what effect will the change have on the total operating expense?

It will be evident on inspection of Table 6, that not all items will vary with the number of trains run. For instance, no change in the salaries of general officers, the cost of advertising, commissions, etc., is likely to result from any practicable change in the number of trains if the traffic remains constant. It is probable that from 50 to 60 per cent of the total operating expense is independent of the number of trains run to do a given business. A much less percentage, perhaps from 20 to 30 per cent, is independent of the number of trains made variable by a varying business. Thus, if a contemplated ruling grade change will save permanently one train a day each way, and the average cost of a train mile is \$1, the saving will be about 2×45 cents a day for each mile of road; while if one train a day is permanently laid off or added by reason of a variation of business, the saving or increased cost may be about 2×75 cents daily per mile of road.

Considerations Affecting the Estimate. — In estimating the portion of expense varying with the number of trains doing a constant business, much intelligent guessing must be done, based on a knowledge of actual conditions on the existing road for which the estimate is made, or on further intelligent guessing of the conditions that will obtain on a proposed road.

An estimate will be made for the average condition of the country, as an example. Such an estimate will require modification in its percentages for any given road and for variations in judgment. In making the estimate the following conditions are considered: —

1. Side track and yards constitute 22 per cent of the total track mileage.

2. The labor put on such tracks per mile is less than that put on main track, — perhaps the ratio is as 1 to 3.

3. Cutting weeds and trimming banks is independent of train mileage, as is also that portion of road-bed repairs, surfacing, etc., due to the effects of weather.

4. Renewals of main line rails is a higher item than it normally should be, because rails not yet worn out are being replaced by heavier rails on account of increased weight of rolling stock and increased business.

5. The same argument applies to locomotive renewals and supplies.

6. Hard ties have a more or less definite life regardless of the traffic, but soft ties fail somewhat sooner under a heavier traffic.

7. About one sixth of all locomotives are switching locomotives, and the items for such locomotives would be but little affected by a change in the number of trains, with no change in the number of cars or loads.

8. Damage to cars may even be less per train mile for lighter trains, but an allowance for this effect is hardly warranted unless there is considerable difference in the weight of trains.

9. Train supplies are partly per car and not wholly per train.

10. The number of switchmen, flagmen, etc., is not wholly dependent on the number of trains run.

11. Accidents are not wholly dependent on the number of trains, about three eighths of the injuries and one fortieth of the deaths being unconnected with the movement of trains.

12. A very small portion of general office expense will vary with the number of trains. Legal expenses will vary somewhat

with the number of accidents, which varies largely with the number of trains.

Some items to which a very small variation of 5 per cent will be allowed, may or may not be affected by a variation in the number of trains; but since they will probably feel such a variation to some small extent, the allowance will be made. Some items which are estimated as unaffected by a variation in the number of trains may in some instances be somewhat affected. Transfer ferries, for instance, are affected by the number of trains crossing on them, but they are very unusual. Allowance should be made on any road using such boats for transferring full trains. Transfer ferryboats handling only cars of freight at terminals would not be affected.

The Estimate. — For change in the number of trains due to change in ruling grade and not to a change in traffic, the items of train-mile cost that will vary and the estimated amount of variation are shown in Table 7. The last column may be taken as the saving or cost per train mile saved or added, at $1 per average train mile; the first column is the average cost of the item for the years 1900 to 1904 from Table 6.

TABLE 7

Table showing items of operating expense varying more or less directly with the number of trains doing a given total business.

	Item	Per cent 1900-'04	Per cent varying with No. of trains	Per cent of whole Cost
	MAINTENANCE OF WAY AND STRUCTURES			
1	Repairs of roadway	10.94	35	3.83
2	Renewal of rails	1.41	70	1.05
3	Renewals of ties	2.81	20	0.56
4	Bridges and culverts	2.54	—	—
5	Road crossings, fences, etc.	0.56	—	—
6	Buildings and fixtures	12.44	—	—
7	Docks and wharves	0.25	—	—
8	Repairs and renewals of telegraph	0.17	—	—
9	Stationery and printing	0.03	—	—
10	Other expenses	0.27	—	—
	Total	21.42	—	5.44

TABLE 7 — *Continued*

	Item	Per cent 1900-'04	Per cent varying with No. of trains	Per cent of whole Cost
	MAINTENANCE OF EQUIPMENT			
11	Superintendence	0.59	5	0.03
12	Repairs and renewals of locomotives	7.20	85	6.12
13	Repairs and renewals of passenger cars	2.14	—	—
14	Repairs and renewals of freight cars	7.56	—	—
15	Repairs and renewals of work cars	0.24	5	0.01
16	Repairs and renewals of marine equipment	0.21	—	—
17	Repairs and renewals of shop machinery and tools	0.65	50	0.33
18	Stationery and printing	0.04	10	—
19	Other expenses	0.54	5	0.03
	Total	19.17	—	6.52
	CONDUCTING TRANSPORTATION			
20	Superintendence	1.75	5	0.08
21	Engine and roundhouse men	9.43	85	8.01
22	Fuel for locomotives	10.95	85	9.31
23	Water supply for locomotives	0.62	85	0.53
24	Oil, tallow, and waste for locomotives	0.38	85	0.30
25	Other supplies for locomotives	0.22	85	0.19
26	Train service	6.85	100	6.85
27	Train supplies and expenses	1.51	50	0.75
28	Switchmen, flagmen, and watchmen	4.84	50	2.42
29	Telegraph expenses	1.78	20	0.36
30	Station service	6.80	10	0.68
31	Station supplies	0.70	10	0.07
32	Switching charges — balance	0.29	—	—
33	Car per diem and mileage — balance	1.56	—	—
34	Hire of equipment — balance	0.24	—	—
35	Loss and damage	0.99	80	0.79
36	Injuries to persons	1.03	80	0.82
37	Clearing wrecks	0.23	80	0.18
38	Operating marine equipment	0.80	—	—
39	Advertising	0.43	—	—
40	Outside agencies	1.52	—	—
41	Commissions	0.08	—	—
42	Stock yards and elevators	0.09	—	—
43	Rents for tracks, yards, and terminals	1.60	—	—
44	Rents of buildings and other property	0.43	—	—
45	Stationery and printing	0.64	50	0.32
46	Other expenses	0.45	5	0.02
	Total	55.45	—	31.68

TABLE 7 — *Continued*

	Item	Per cent 1900-'04	Per cent varying with No. of trains	Per cent of whole Cost
	GENERAL EXPENSES			
47	Salaries of general officers	0.92	—	—
48	Salaries of clerks and attendants	1.27	5	0.06
49	General office expenses and supplies	0.25	5	0.01
50	Insurance	0.41	—	—
51	Law expenses	0.56	20	0.11
52	Stationery and printing (general offices)	0.17	5	0.01
53	Other expenses	0.38	5	0.02
	Total	3.96	—	0.21
	RECAPITULATION			
54	Maintenance of way and structures	21.42	25.4	5.44
55	Maintenance of equipment	19.17	34.0	6.52
56	Conducting transportation	55.45	57.1	31.68
57	General expenses	3.96	5.0	0.21
	Grand Total	100.00	43.85	43.85

The final figure 43.85 may be regarded as the cost in cents that would be saved or added per mile of road by cutting out or adding one train one way with no change in business. The full figure will perhaps not be reached, since if the number of trains is decreased by increasing the weight of all maximum trains, the running cost of these trains is increased perhaps 1 per cent for each 10 per cent of increase of weight, and if the number is increased by decreasing the weight, a similar decrease in train-mile cost may be estimated.

Again, if the train mileage is permanently changed, the number of locomotives will vary, and fixed charges — interest on invested capital — will be affected. This item may be estimated at 1 cent per train mile, making the total allowance in round numbers 45 per cent, or cents.

It is not likely that the truth lies more than 10 per cent either side of this figure. In any given case the figure as a percentage

should be multiplied by the assumed or known train-mile cost expressed in dollars. If a saving in number of trains is due to the introduction of heavier locomotives, the train-mile costs of all maximum trains will be increased perhaps $1\frac{1}{2}$ per cent for each 10 per cent increase in weight of train.

CHAPTER XVI

DISCUSSION OF THE EFFECT OF DISTANCE, RISE AND FALL, AND CURVATURE, ON TRAIN MILE COSTS

Method of Comparison. — For the purpose of dividing train-mile cost among the several items, distance, rise and fall, and curvature, some average conditions must be assumed that are comparable. The work done in drawing an average train a mile will be used as a unit of comparison. Not all items of cost will vary with the work done, and not all will be alike affected by the three elements of distance, rise and fall, and curvature.

The average American freight train weighs not far from 750 tons and runs at perhaps 15 miles an hour, and will be considered to be half loaded. This train weight will seem small, and is small for any average traffic main line. The figure would need revision for any given case, but the total weight is not material to this discussion.

At 15 miles an hour a half-loaded train will have a resistance of perhaps 5.4 pounds per ton. A mile of grade offering the same resistance, and a mile of curve offering the same resistance will be considered to require the same expenditure of energy, and hence to cause the same variation in those items of expense that may be considered to vary with the power output. To distance will be assigned also an effect on a number of other items independent of power, and to curvature an item of roadway maintenance that is independent of power or number of trains.

The cost of a stop will be considered as equal to the cost of operating a mile of distance, and a stop once in 10 miles will be assumed, making the cost for stops one tenth the cost of running distance. Stations are generally less than 10 miles apart, but not all trains stop at all stations.

Rise and Fall Defined. — Rise and fall is considered to be the rise in feet on an ascending grade and the corresponding feet of fall on some descending grade. If a line be all up grade in one direction, and consequently all down grade in the opposite direction, the rise and fall is the difference in terminal elevation. If it be undulating, the total rise and fall is determined by adding the vertical feet of all sags and summits of the undulations, giving as a result the difference in terminal elevations plus the sum of all summits and sags above or below a uniform grade line. This is the rise and fall of the constructed line. The operating rise and fall is likely to be quite different, due to the difference between the actual and the velocity profiles. The operating profile is the velocity profile; and in estimating difference in cost, this profile should be used for all grade questions. It will show the effect of starting and stopping, the stretches over which the locomotive is working, those over which steam is shut off, and those on which brakes are applied.

Let the profile of Fig. 80 be considered. It is drawn to a very much exaggerated vertical scale. The full line is the track profile, the dotted line the velocity profile, starting from rest at station 0, and moving to the right. The train is supposed to be the maximum train considered in Problem 2, page 190.* The track profile would have its curves well rounded off, but the figure will serve for an illustration.

It will be noted that whereas the locomotive is loaded for a 1 per cent grade, there is no difficulty in making the 1.3 per cent grade, and the top of the hill is reached with a speed of about 12.6 miles an hour. The locomotive may continue its efforts across the summit, but it will be better to shut off steam when station 110 is safely reached, in order to lessen the use of brakes on the down grade. The resistance of the summit level is just about enough to reduce the speed to 10 miles when the train starts down the long 1 per cent grade. When the speed reaches 30 miles an hour, which it does in about 4100 feet, brakes must be applied. The speed will then be held as nearly as may be at 30 miles to

* The student should verify this velocity profile as a problem in velocity grades.

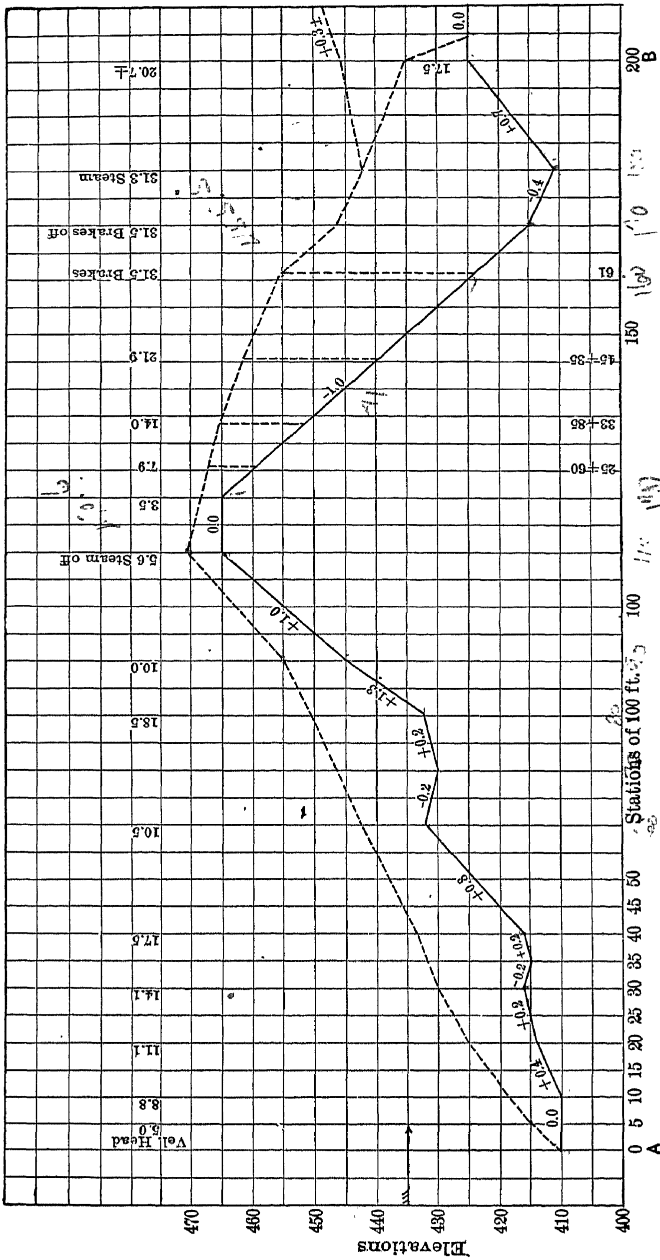

Stations of 100 ft.
Elevations
Vel. Head
5.6 Steam off
31.5 Brakes
31.5 Brakes off
31.3 Steam

Fig. 80

station 170, when the following grade for 2000 feet being almost exactly the grade of repose for the speed, brakes are released, but steam is not again used until station 180 is reached. If a stop be desired at a point not far beyond station 200, no steam need be used, the grade serving to check the speed, brakes being required somewhat just at the stop. If 32 to 33 miles be considered safe, brakes need not be used on the 1 per cent grade. The rise and fall by the track profile between A and B is 72 feet; by the velocity profile it is 64 feet. If a stop were to be made on the level grade to the right of B, the velocity profile rise and fall would be ~~60.6~~ feet.

Authors differ in their treatment of rise and fall. If a small rise or sag in an otherwise uniform grade line occurs, it is considered to be an addition to the rise and fall, even though the grades be all ascending or descending, and hence add nothing to the elevation through which the train is lifted or dropped. Such humps and sags interfere to some slight extent with the uniform work of the locomotive, and hence may add some small amount to the cost of the operation of an otherwise uniform grade line, but the effect is not measurable so long as the steeper portions are within the ruling grade rate. It is sometimes estimated that a sag is a positive benefit, increasing the speed through its length over what would have obtained on a level. The matter will be discussed in another paragraph.

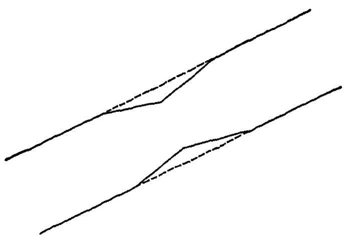


Fig. 81

Classes of Rise and Fall. — Three classes of rise and fall have been generally recognized: —

Class A. — Rise and fall apparently not felt by the locomotive, as the 3 feet at stations 60 and 70 of the profile, Fig. 80. No power effort to overcome such rise and fall seems to be made; its effect is simply to vary the speed somewhat.

Class B. — Rise and fall requiring full power in the ascent,

the shutting off of steam in the descent, but not the use of brakes.

Class C. — Rise and fall requiring the use of brakes and sometimes of sand in the descent, and the whole power of the locomotive in the ascent.

Figure 80 shows all three classes.

There are plainly 3 feet on the track profile that make no showing whatever on the velocity profile.

There are apparently 45 feet of Class B on the track profile, but only about 19 feet on the velocity profile. There are about 9 feet on both profiles of Class C. All this is in addition to the difference in elevation of the two termini. This difference will not be properly a part of either of the three classes. The locomotive must lift the train through this height, going from the lower to the higher point, and theoretically the work necessary to do this is all recovered in going with a similar train from the higher to the lower point. But as trains are usually worked, this result does not obtain. What portion is recovered may not be known. If the straight grade from terminus to terminus be not steeper than about 0.40 per cent, which is the grade of repose for safe high speed, the difference in level may perhaps be estimated under Class B. Termini must be considered to be ends of operating divisions. In comparing two lines between the same termini, only the rise and fall over and above the difference in terminal elevations should be considered.

In Fig. 80 if there be a stop on the level grade beyond B, brakes would be required for a short distance, adding somewhat, — about 10.7 feet to the Class C rise and fall, — making in all 19.7 feet of this class.

If the train be supposed to enter from the right with a speed of 25 miles an hour, the velocity profile will show no Class C grades until the stop at A necessitates a drop of about 22 feet; but as before, steam will be shut off at the summit, and the entire run down the grade to A will be by gravity. The entire rise and fall, therefore, except the 3 feet at station 180, is of Class B, and excepting also the 22 feet of Class C at the stop.

There may be some question as to whether rise and fall of starting and stopping should be considered. If starting and stopping are estimated separately, the rise and fall due to it should not be counted on the velocity profile. It is probable, too, that the braking at the stop is more costly than the partial use of brakes on a grade, which is warrant for considering it separately.

Rules are often given for determining the amount of rise and fall from the track profile, but the author knows of no rule that will give even closely approximate results for a profile like the figure. The probable velocity profile should be drawn for movement in both directions and the resulting quantities averaged. It is true that not all trains will find the same amount of rise and fall. A passenger train with 50 or 60 miles an hour allowable speed might find 60 feet more of rise and fall, none of which would require the shutting off of steam.

When the profile is a series of short undulations, no sags or summits of more than 15 or 20 feet, it is entirely probable that the whole rise and fall is of Class A, except the difference in elevation of termini. Sags of even 25 feet or more may be of this class, but are not likely to be for freight trains. It can rarely be true — as is often stated — that the draw-bar pull may be made constant through an undulating grade. Such a grade will rarely show an absolutely level velocity profile, because as the speed changes the tractive effort of the locomotive changes, and the train resistance changes.

Rise and Fall Equivalent to a Mile of Distance. — In estimating cost of rise and fall, all of the track profile rise and fall that the velocity profile shows to be of Class B, will be estimated to cost half the cost of lifting a train through the vertical feet indicated. This assumes that half the energy stored in the train on the summit is recovered. For Class C, none of the energy so stored is recovered; and, moreover, some work is done by the brakes in lowering the train. This work is a negative tractive effort equal to the grade effort of the grade on which the train is, less the grade of repose for the maximum speed. If this grade of repose be 0.4, and the operated grade be 1 per cent, the brake effort must

be equivalent to the grade effort of a 0.6 grade; if the operated grade be 2 per cent the brake effort must equal the grade effort of a 1.6 per cent grade, or $2\frac{2}{3}$ times the effort required on a 1 per cent grade. In operating, say, 10 feet of fall on such grades at the constant speed of 30 miles, the work done in braking would be: For the 1 per cent grade (grade resistance for a 0.6 grade): —

12 pounds × 1000 feet = 12,000 foot-pounds per ton of train.

For the 2 per cent grade (grade resistance for a 1.6 grade): —

32 pounds × 500 feet = 16,000 foot-pounds per ton of train, or one third more than on the 1 per cent grade.

The time required on the 2 per cent grade is half that of the 1 per cent grade, hence with an equal work done the power required would be at twice the rate for half the time, or the same total of horse-power hours. Since the work is one third more, the power expenditure is one third more. It is evident, therefore, that the cost depends not only on the feet of rise and fall, but on the rate of grade on which it occurs.*

If the descending velocity grade, parallel to the corresponding track grade, be greater than about 0.4, approximate grade of repose for assumed safe speed, the power expenditure ratios and consequent cost ratios (assuming cost proportional to power) will be about as follows for the grades given, assuming the power loss on a 0.67 per cent grade as unity, since by the discussion below this loss corresponds about to the power consumed in running a mile of distance.

TABLE 8

Grade per cent	0.4	0.5	0.67	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Relative power loss	0.0	0.41	1.0	1.49—	1.81+	1.99—	2.08—	2.15	2.19	2.23

* The brake pressure will not be proportional to the grade effort since automatic brakes have not been so devised that the engineman may control the pressure at will. The result is that brakes must be applied with full force until the speed has been reduced so that the brakes may be released and again applied when speed has been again increased to the maximum. This method of application is probably more costly than steady braking at the proper pressure.

The average resistance of an average train running at 15 * miles an hour has been assumed at 5.4 pounds per ton. This corresponds to a 0.27 per cent grade. The work done in climbing 1 mile of such grade, then, equals that done in running 1 mile of straight, level track. One mile of such grade gives $14\frac{1}{4}$ feet of rise and fall. If a train be lifted through this distance, the work done is $2000 \times 14\frac{1}{4} = 28,500$ foot-pounds per ton, or the same as that required to draw the train 1 mile on straight, level track. If the speed be greater, the resistance and consequent rate of grade are higher, and the result is a greater number of feet rise and fall to equal a mile of distance; but stiff grades are usually taken at low speed — hence the figures.

Since rise and fall of Class B is assumed to cost half the expense of lifting a train through the vertical feet in any case, then for this class $28\frac{1}{2}$ feet of rise and fall will be considered to equal the power expense of running a train 1 mile on a straight, level track.

For Class C the cost depends on the grade. A descent on a 0.67 per cent grade requires negative work equal to that expended in lifting on a 0.27 per cent grade, and the work is largely expended in the injurious wear of brake shoes and wheels, hence $14\frac{1}{4}$ feet rise and fall of Class C on a 0.67 per cent grade will be estimated to cost $2\frac{1}{2}$ times the power expense of running a train 1 mile on a straight and level track, and for other grades the cost will be estimated thus: $14\frac{1}{2}$ feet ascent at the cost of power used in running a mile of distance, $14\frac{1}{2}$ feet of descent at $1\frac{1}{2}$ times this cost multiplied by the factors indicated in Table 8, page 223.

The additional cost when the velocity profile shows an actual ruling grade, cannot be well determined. Mr. Wellington adopts 3 cents per train for both classes for the number of vertical feet assumed to equal a train mile. Mr. Berry † adopts the same sum. This is stated to be for wear and tear of track and roadbed. It should perhaps be about the same for both classes, and yet it must be somewhat greater on very steep grades than very

* Where other speeds are used, other resistances and grades will result.

† "Reduction of Gradient, etc., on the Union Pacific Railroad."

light grades. The method of analysis used in this book, and the character of the result, lead to the suggestion that very little, if any, increase over the figures here given should be allowed. All expenses that vary with the power output will be considered to be affected by rise and fall. Although on steep descending grades the items will vary from those used for Class B, the separation is difficult and the cost is simply taken proportional to the power wasted.

The effect of rise and fall on speed must be considered more carefully before what constitutes Class A can be fully understood. Let the train considered in the problem of Chapter XIII, running at full possible speed, say 32+ miles an hour on a level, approach a 0.928 per cent grade 30 stations long. If the locomotive develops its utmost power throughout the run, the train will reach the summit of the hill shown in the figure at a speed of approximately 20 miles. The velocity grade will be the curved dotted line rather than the assumed straight line, and the figures are not exact. If still on the down grade the utmost locomotive effort be used, the train will again be running at 32 + miles an hour in about 19.4 + stations. If the drop equals the rise, the speed will be greater than the speed of approach, if no change in the working of the locomotive is made. Therefore, a given elevation in a sag, bringing out the maximum safe speed, cannot again be reached after an intermediate summit without changing the power output of the locomotive. It is not practicable to maintain a constant locomotive pull with the varying speed. This has not been generally understood, and the hill of Fig. 82, even if the descent equaled the ascent, would usually be considered Class A rise and fall. About one third of it would be Class B if 32 miles an hour is not to be exceeded. The average speed over the summit is approximately 26 miles an hour instead of about 30 miles, which it would be if the grade were uniform from *a* to *b*.

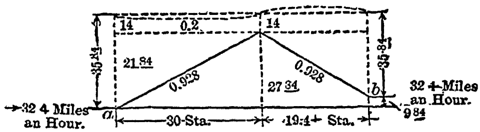


Fig. 82

If the grade were approached at 20 miles an hour, the speed at the summit would be about 13 miles, and after an equal fall on the down grade would be about $32\frac{1}{2}$ miles. Such a grade is wholly of Class A, as usually estimated. The average speed would be about 19 + miles an hour. If the grade had been level, the speed might have been approximately 26 miles an hour, rather less, perhaps. The time required to operate the hill would be about one third more than that required to operate the level. It would certainly cost something.

A succession of such hills such as this — all Class A — would increase the time between termini about 15 per cent, which would certainly affect train wages, possibly even the number of trains; a single hill would have no such effect.

But let the effect of a sag below the grade line be considered. If the train approach the sag at 20 miles an hour, its speeds would be approximately as shown in Fig. 83. The average speed through the sag will approximate 27 miles an hour. If the stretch were level, the speed would approximate 24 miles an hour,

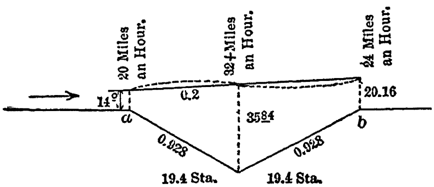


Fig. 83

but with a trifle higher speed at the end of the stretch. The time here by the sag is about 89 per cent of that by the level line. It is thus seen that a sag may be of positive benefit, while a summit is always a positive injury unless a stop is required, when it may be helpful. This result leads to what appears to be an absurd conclusion, namely, that if a naturally level line be built so as to form a succession of grade sags, it will be a better line than if built level. But this is not true, because if a second sag like that of Fig. 83 were to follow it at once, and if the locomotive were to be driven still at its utmost, a speed faster than the safe limit would be reached, requiring the shutting off of the steam and loss of power. Moreover, the condition of constant utmost effort of the locomotive cannot be realized. Such a sag is a positive benefit just out of a starting-point and is an advisable construction

where the station cannot be on a natural summit. The offsetting effects of occasional summits and sags of Class A account for the common statement that no expense attaches to this class.

To determine what part of the total rise and fall belongs to Class A requires the construction of the velocity profile. When this is done, all summits and sags of the track profile indicated by the velocity profile as belonging to Class A should be set against one another and the result charged, or credited, as the case may be, with, say, one fifth the cost assigned to Class B. The whole estimate for Class A rise and fall is purely guess-work, but the item is always a minor one and no serious error is likely to occur if the guess is 100 per cent out of the way.

Curvature. — The curve that will offer resistance equal to that of straight and level track, that is, 5.4 pounds per ton, assuming a 6-foot truck to allow for the few cars with such trucks and the longer wheel base of the locomotive, is approximately a 12-degree curve. A mile of such curve contains 630 degrees, which will therefore be assumed to entail a cost equal to twice the power expense of a mile of distance, with a further allowance for maintenance of way and accidents. Twice the distance cost is used because the power expended is almost wholly used to wear the wheels, brake shoes, and rails, and while this sort of power expense may not be at the same rate as power produced by fuel and water, no more rational method of estimating has occurred to the author, who thinks that estimates of rail and wheel wear due to curves are likely to be fully as wide of the true mark as an estimate of the cost of power. It is not possible to compensate all curves, and it is customary to compensate only on the steeper grades, so that the major portion of curvature is uncompensated. Compensated curves cost just as much as uncompensated curves, but half this cost — the steam power — is sometimes estimated in the rise and fall. It will not be so estimated here.

Some portion of the maintenance of way expense due to curvature is independent of the degree of the curve, and exists because the track is curved rather than straight, necessitating more labor in alignment, levels, surfacing, etc.

Division of Expense. — There are about 12 feet of rise and fall per mile of American railroads. Much of this is Class A, for which the cost is very small, probably the greater portion is of Class B, and some is of Class C. For the purpose of a comparative estimate it will all be averaged as of Class B. The additional cost of running 1 train mile, therefore, for those items that vary with work done over that necessary to run a mile of straight level track, is $\frac{12}{28.5}$, or 46 per cent. For any given road actual figures will be known.

There are about 30 degrees of curvature per mile of American railroads. The increase in cost due to curvature, then, is $\frac{2 \times 30}{630}$, or about $9\frac{1}{2}$ per cent. Nine per cent will be used.

The cost of stopping and starting is assumed to increase running expense 10 per cent. For those items that vary with all the elements considered, the division of cost is found thus: If a be the cost for distance and k the total cost varying with trains run,

$$a + 0.46\,a + 0.09\,a + 0.10\,a = k.$$

Then the cost of distance is $\frac{100}{165}\,k$, rise and fall $\frac{46}{165}\,k$, curvature $\frac{9}{165}\,k$, and stops $\frac{10}{165}\,k$.

For those items not affected by rise and fall, the sum will be similarly divided among the other three.

About 55 per cent of roadway expense will be assumed to vary with distance and curvature, and to be independent of the trains run. About 75 per cent of American track is straight. Assuming that maintenance of curved track costs 150 per cent of the maintenance of straight track, about 37 per cent of the total item of roadway maintenance may be attributed to distance, regardless of trains, and 18 per cent to curvature. While some portion of curved roadway maintenance is independent of the degree, it would be practically impossible to separate it.

About 70 per cent of tie renewals will be attributed to distance only, regardless of trains, together with 100 per cent of maintenance of telegraph and fences.

Other items will be assumed affected as indicated in the following table: —

TABLE 9

COST PER TRAIN MILE OF OPERATING DISTANCE ONLY (AVERAGE TRAIN-MILE COST ASSUMED AT $1).

	Item		Per cent of Whole Expense	Per cent Varying with Distance	Distance Cost per Train Mile Cents or Per cent
1	Repairs of roadway		10.94	31.8	3.48
2	Renewal of rails		1.41	46.9	0.66
3	Renewal of ties		2.81	20.0	0.56
4	Bridges and culverts	Except fencing, must be estimated for each special case			
5	Road crossings and fences				
12	Repairs and renewals of locomotives		7.20	50.00	3.60
13	Repairs and renewals of passenger cars		2.14	40.0	0.86
14	Repairs and renewals of freight cars		7.56	40.0	3.02
15	Repairs and renewals of work cars		0.24	20.0	0.05
17	Repairs and renewals of shop machinery and tools		0.65	29.2	0.19
21	Engine and roundhouse men		9.43	72.7	6.86
22	Fuel for locomotives		10.95	50.00	6.08
23	Water supply		0.62		
24	Oil, tallow, and waste		0.38		
25	Other supplies		0.22		
26	Train service		6.85	86.7	5.94
27	Train supplies		1.51	43.3	0.65
29	Telegraph expenses		1.78	17.5	0.31
33	Car per diem and mileage		1.56	50.0	0.78
35	Loss and damage		2.25	50.0	1.13
36	Injuries to persons				
37	Clearing wrecks				
51	Law expenses		0.56	12.5	0.07
	Total				35.24
	Add for superintendence and other expenses				0.06
	Total				35.30

Cost of Distance. — At \$1 per train mile \$0.353 is the sum that may be saved or must be expended per train mile saved or added by reason of changes in distance. To the annual saving or cost must be added that portion of annual maintenance of way costs that is independent of train mileage. As an average for the country this may be taken at \$350 per mile of single main track. If there are N daily round trip trains, the annual cost in round numbers is, $365 \times 2 \times N \times \$0.353 + \$350$ per mile of single track added. For any other train-mile cost than \$1 the entire sum should be increased or diminished proportionally. It must be understood that the figures are to be made anew for any given road, those given being the average for the United States. If the change is but a few feet in the aggregate less than, say, 1000, perhaps 80 per cent of the foregoing values should be used. If the distance is such that stations and sidings must be considered, probably 125 per cent of the given values will be nearer the truth. When the distance is so great as to mean new freight divisions, as it might be in some new lines yet to be located and built in the United States and abroad, probably 80 per cent of all expenses may be attributed to distance only, not because directly caused by distance, but because all expenses will be increased and distance is the most convenient unit for estimates.

Against this must be put the diminished or increased revenue due to saving or increasing distance. While this is an item that varies very much with the road, it is probably not far from the truth to say that as an average for the United States from 40 to 50 cents per passenger train mile will be lost for lessened distance, or gained for increased distance of moderate amounts. Freight revenues, while they may be modified by small changes in distance, are so arbitrarily fixed, that no general estimate of loss or gain can be made. Differences in distance great enough to much affect the time between termini may result in added or lessened business; but small differences, such as the engineer usually has to consider, will have no such effect.

Considering only the passenger revenue, the average offset per train mile, all trains, in the United States, may be about 20

cents. This figure in particular must be considered anew for any given case. Between competitive points, it is likely to be nothing, but much of the travel will always be between local non-competitive points.

Cost of Rise and Fall. — It has been estimated that 28.5 feet of Class B rise and fall will cost as much as the power-varying items of a mile of distance. Referring to Table 9, page 229, it will be assumed that the costs attributed to distance for the following items will vary with the power output: All engine supplies, half of locomotive repairs and renewals, one fourth of engine and train service, and one fourth of shop tools and machinery. These items are seen to sum 11.13 cents at $1 per train mile. Therefore, one train foot of Class B rise and fall will cost about 0.39 cents. This is considerably in excess of usual estimates. It is so because average train resistance has been taken at a lower figure than is generally assumed to be correct. This results in nearly twice the usual assignment to rise and fall, the remaining increase being due to difference in judgment.

Class C will show an even greater increase, believed to be wholly wise. For this class 14¼ train feet of ascent are assumed to use as much power as a mile of distance, and the same number of feet of descent, a varying amount of power depending on the rate of grade. For the ascent the train-foot cost, then, is 0.78 cents. For the descent it is on the grades named, as in Table 10.

TABLE 10

COST OF CLASS C RISE AND FALL

(Train-mile cost $1)

Grade	0.4 and under	0.5	0.67	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cost per foot — descent	0.0	0.48	1.17	1.74	2.12	2.33	2.43	2.52	2.56	2.61
Cost per foot — ascent	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Total cost per train foot in cents at $1 per train mile	0.78	1.26	1.95	2.52	2.90	3.11	3.21	3.30	3.34	3.39

While the same total power cost has been used in this estimate for Class C rise and fall, it is true that it arises from a somewhat different set of items, the descent showing principally in wasted steam, in rail wear, and in repairs of cars and locomotives. Class C will also affect train wages, which is generally denied. The *rate* of a ruling grade determines the number of trains and the speed, but the *length* of that grade — the amount of rise and fall — determines the time required to make the hill after the speed has been fixed.

Class A rise and fall, estimated at one fifth the cost of Class B, will be assumed to cost or save 0.08 cents per train foot, according as it is caused by a summit above or a sag below the general grade line. In making preliminary estimates it may be neglected.

Cost of Curvature. — It has been assumed that 630 train degrees of curvature will cost twice as much as the sum total of all items varying with power output for a train mile of distance. From Table 9, this gives 22.26 cents. Therefore with a small allowance for accidents, a train degree will cost 0.038 cents, to the annual cost due to which must be added the annual cost of maintenance of roadway that varies because of curvature but is independent of the number of trains. This may be taken at $3.67 per degree of curvature. If N be the number of daily trains making round trips, the annual cost for curvature per degree may be

$$2 \times 365 \times N \times \$0.00038 + \$3.67.$$

It may be that 500 degrees is a better figure to use as the equivalent of a mile of distance. Using this figure gives

$$2 \times 365 \times N \times \$0.00048 + \$3.67.$$

The cost per degree of curvature per year per daily train round trip is found from the two foregoing values to be respectively

$$\$0.28 + \frac{\$3.67}{N}$$

and

$$\$0.35 + \frac{\$3.67}{N}.$$

Curvature is probably more costly per train on roads of heavy, fast traffic, hence it may be well to use a value approximating the smaller cost for light traffic lines, and one approximating the larger cost for heavy traffic lines.*

Cost of Pusher Service. — Assistant engine service, usually called pusher service from the custom formerly prevailing of attaching the assistant engine at the rear of the train, is usually expensive service for the reason that it is almost always on grades giving rise and fall of the worst class, and costing on an average probably not less than 5 cents a mile run for this item only. The smaller crew makes wages less by perhaps 6 or 7 cents a mile. Pusher service is also apt to be intermittent, but the locomotive runs light on the down grade, the fuel cost being less than for the through locomotive on the same grades, but probably more than for the average of the through locomotive. On the whole, if the assistant locomotive may be kept as busy as the through locomotive, its mileage cost should not differ much from that of the through locomotive and train, less expenses due to cars, or about 30 cents per mile run. Per train mile helped there must be two pusher miles, hence, adding 1 cent per mile for interest on the cost of the assistant locomotive, 62 cents per train mile helped will be perhaps a fair estimate for this service. Any given case should furnish reliable figures.

To put this estimate on the basis of the daily train helped, the cost is \$0.62 per daily train per mile of incline. This is for a train-mile cost of \$1, and is to be multiplied by the train-mile cost in dollars. If N be the number of daily trains helped, the annual cost per mile of incline at \$1 per train mile is

$$N \times \$0.62 \times 365 = \$226.30\,N.$$

* The cost of curvature is a very difficult item to determine with any degree of certainty; there is a tendency to place it at a higher figure than formerly, justified by the continually increasing weight of locomotives and cars. The figures given above seem to include the best present practice (1907) and to allow for some further advance.

A round number of from \$225 to \$250 may be used for estimates. If the assistant locomotive is not kept busy, the cost per train will be increased. If the helper grade is near a large station where the helper locomotive may be kept busy when not assisting a train up the grade, the cost will be about as given.

CHAPTER XVII

PROBLEMS IN CHANGE OF RULING GRADE, DISTANCE, RISE AND FALL, AND CURVATURE

1. To find the Saving Due to a Reduction of Ruling Grade. — Let the reduction be 0.2 per cent on a 1 per cent ruling grade on a division 180 miles long, using the locomotive of the problems in Chapter XIII.

A train-mile cost of $1.24 is assumed, with six passenger and twelve freight trains daily, six slow trains making an average of 18 miles an hour, 12 miles on the ruling grade, five fast trains making 22 miles an hour, 15 miles on the ruling grade, and one way train unaffected by the rate of the ruling grade.

The number of trains for varying ruling grades will be roughly inversely as the maximum possible load behind the tender, excluding the caboose of, say, 15 tons.

The maximum trains affected by the change are six slow trains at 12 miles on the ruling grade, and five fast trains at 15 miles on the ruling grade. By the method of Problem 2, page 190, the loads that can be handled behind the tender, less 15 tons for caboose, at the two speeds, are

	12 miles	15 miles
1.0 per cent grade	1120 tons	848 tons
0.8 per cent grade	1373 tons	1044 tons

Therefore there may be

$\frac{1120}{1375} \times 6 = 4.86$ daily slow trains on the 0.8 per cent grade,

$\frac{848}{1044} \times 5 = 4.05$ daily fast trains on the 0.8 per cent grade.

The saving is 2.09 daily trains. The fraction is allowable because the number of daily trains is an average of one or more years' running. The road having an average train-mile cost of \$1.24 probably has an average freight train-mile cost of about \$1.42 and passenger-train mile cost of \$0.88. All freight trains will be assumed to cost \$1.42 per mile run.

The daily saving in train mileage is

$$180 \times 2.09 \times 2 = 752.4.$$

Only 45 per cent (page 215) of the estimated cost of these train miles is saved, or $0.45 \times \$1.42 = \$0.639$ per train mile. The annual saving may therefore appear to be, but is not,

$$752.4 \times 365 \times \$0.639 = \$175{,}486 + .$$

The saving might be approximately this sum — and it has heretofore usually been thus estimated — were it not that the maximum trains on the revised line are heavier than those on the original line, and hence, because more work is required to pull them over the unrevised portions of the line, and because a somewhat slower schedule may be necessary, — this will depend on the characteristics of the line, — the maximum trains of the revised line will cost more per mile run than would the lighter trains of the original line.

The new train-mile cost is usually found by dividing the new cost per mile by the new number of trains, thus:

$$\frac{18 \times \$1.24 - 2.09 \times \$0.639}{18 - 2.09} = \$1.31895.$$

No mathematical analysis can predict with precision what the new train miles will cost, but the following approximation is probably sufficiently exact for the purpose and errs, if at all, on the side of safety in that it makes the contemplated improvement a little less rosy than would appear from the investigation thus far made. Dividing the train-mile cost of \$1.319 between passenger and freight trains in the proportion of 5 to 8 gives approximately \$0.96 per passenger-train mile and \$1.536+ per freight-train mile; increasing the latter by 2 per cent for 8.91 trains that have been increased in weight by about 20 per cent (see page 215), and using the results for a new average train-mile cost gives for that average

$$\frac{6 \times \$0.96 + 1 \times \$1.536 + 8.91 \times \$1.567}{15.91} = \$1.3361 + .$$

Something like this train-mile cost may be expected and

$$8.91 \times .02 \times \$1.536 \times 365 \times 2 \times 180 = \$35,960+$$

is the annual loss to be deducted from the previously determined annual saving because of the heavier trains. The net annual saving, then, is \$139,526, and this sum divided by the market rate of interest gives the value, or capitalized value, of the saving due to the reduction in grade, or the limit of justifiable expenditure to secure the reduction.* At 5 per cent this value is \$2,790,520.

The foregoing investigation supposes the grade reduction to be accomplished by reducing the rise and fall. If it is done by increasing the distance without reducing the rise and fall, there will be no such justifiable expenditure. The cost of operating the extra distance with the heavier trains must be considered, and it is easy to see that a limiting case might arise in which the supposed gain from the grade reduction would be wholly lost. Each case must be investigated for itself with all its known conditions.

2. **To find the Saving Due to a Reduction of Distance.** — Let the reduction be 1.8 miles on the division of Problem 1, before the grade reduction.

The expense of all trains is affected by this item, therefore the annual saving is (see p. 230)

$$(18 \times 2 \times 1.80 \times 365 \times 0.353 + 350 \times 1.8)\ \$1.24 = \$11,134.15.$$

This divided by the prevailing rate of interest is the value of the saving or the limiting expenditure to secure it. At 5 per cent this sum is \$222,683.

If the reduction of grade is made, the saving will be

$$(15.91 \times 2 \times 1.8 \times 365 \times 0.353 + 350 \times 1.8)\ \$1.3361 = \$10,701.79,$$

and this capitalized at 5 per cent is \$214,036.

It is the second rather than the first value that must be added to the value of grade reduction to determine the total saving if the contemplated improvement includes both grade and distance changes. And it is the second value that must be subtracted from

* On an existing division of road known to the author where conditions approximate those of this problem, the grade reduction could probably be made for less than one quarter the apparent value or limit of justifiable expenditure.

the value of grade reduction if that reduction is secured by increasing the length of the line.

The value of saving 1 mile on this line, before the grade reduction, is \$123,713, or, say, \$120,000. The value of saving 1 foot (distances less than 1000 feet) (see p. 230) is \$18.75, or, say, \$18.

Against these values should be put whatever loss in revenue may be estimated to arise by reason of the lessened distance.

3. To find the Saving Due to a Reduction of Rise and Fall. — Let the reduction be 7 feet Class C, 14 feet Class B, and 10 feet of summits of Class A, rise and fall on the road of Problem 1 before the grade reduction.

It will be assumed that the velocity profile shows the Class C rise and fall to be on 1 per cent grades, and to be Class B for passenger trains, and that Class A affects all trains.

There are, therefore, for all trains, 10 feet of Class A, for freight trains, 7 feet of Class C, and 14 feet of Class B, and for passenger trains, 21 feet of Class B. Therefore, the saving on this road for the several classes will be (p. 231):

Class A	$18 \times 2 \times 10 \times 365 \times \$0.0008 \times 1.24 =$	\$130.35
Class B	$6 \times 2 \times 21 \times 365 \times 0.0039 \times 0.88 =$	315.67
Class B	$12 \times 2 \times 14 \times 365 \times 0.0039 \times 1.42 =$	679.18
Class C	$12 \times 2 \times 7 \times 365 \times 0.0252 \times 1.42 =$	2194.27
		\$3319.47

Capitalized at 5 per cent the value of the saving is \$66,389. If the reduction of rise and fall is due to the ruling grade reduction, the value of the saving should be computed on the daily trains and train-mile cost of the reduced gradients.*

4. To find the Saving Due to a Reduction of Curvature. — Let the elimination of 20 degrees of curvature from the road of Problem 1, before the grade reduction, be considered.

All trains are affected by this item, therefore, assuming a round number cost of \$0.0004 per train degree for those items varying with the number of trains (page 232),

$$(18 \times 2 \times 20 \times 365 \times \$0.0004 + \$3.67 \times 20)\ 1.24 = \$221.36.$$

* The student may make this computation. He may also compute the value of saving 1 foot of rise and fall of the several classes.

The value of this at 5 per cent is \$4427.20. The value of saving 1 degree of curvature is one twentieth of this sum, or, say, \$220. If the elimination be the result of the grade reduction improvement, the saving is

$$(15.91 \times 2 \times 20 \times 365 \times \$0.0004 + \$3.67 \times 20)\ 1.3361 = \$222.21.$$

The value of this at 5 per cent is \$4444.20. This is the value that must be used in computing the total benefit of the whole improvement. It will be noted that the effect is greater for the improved line than the original line, while the reverse is true of the distance values. This fact results from the greater relative value of the term independent of number of trains in the curve formula.

5. **To find the Cost of Helper Service.** — It is found that there will be much difficulty in reducing one of the hills on the division of Problem 1, and the cost of using a helper engine will be considered. If the helper is used, the line may still be operated as a 0.08 per cent grade. The helper grade is 4 miles long.

There will be 8.91 daily trains to be assisted over the hill which has the ruling grade on one side only. The daily mileage to be made by the helper will then be $8 \times 8.91 = 71.21$ miles, or only about seven tenths of a day's work for a single locomotive. The remaining three tenths will probably cost half as much as an equal number of miles run. Therefore it may be said approximately, that the annual cost of the helper service will be (page 233)

$$1.3361\ (8.91 \times \$226.30 \times 4)\ (1 + \tfrac{1}{2} \times \tfrac{3}{7}) = \$13,085.25.$$

The value of this at 5 per cent is \$261,705; and if the hill can be reduced for this sum and the money is available, it would better be done.

6. Comparisons. — To compare possible locations not yet constructed, and having different lengths, ruling grades, amounts of rise and fall, and curvature, some probable number of daily trains for one line and a train-mile cost are assumed, and from the ruling grades the number of trains on the second line is determined together with the train-mile cost. The corresponding ruling grade value of one line over the other may then be found. If the higher-grade line has been selected for a basis,

the low-grade line will show an advantage to which must be applied, with the proper sign (plus or minus), the values of the differences in distance, rise and fall, and curvature, of the two lines. If the low-grade line has been selected for a basis, the high-grade line will show a disadvantage to which must be similarly applied the items of distance, rise and fall, and curvature.

For ruling grade comparison the two lines are assumed of equal length, that of the shorter. The excess of distance of the longer line is figured as a disadvantage at the train-mile cost and number of trains for that line, or as an advantage to the shorter line, depending on which has been selected for the basis, at the train-mile cost and number of trains for that line. To compare rise and fall, and curvature, the totals for each line are figured for their respective numbers of train and train-mile costs, and the differences in value applied as indicated in the preceding paragraphs.

To compare two lines varying only in the minor items of distance, rise and fall, and curvature, the difference of these items will be estimated for the assumed or known daily trains and train-mile cost of the line.

To compute the value of helper service, the number of trains actually to be helped must be determined, and a train-mile cost, figured on the basis of the lessened number of trains made possible by the helper, must be used.

PART III

RAILROAD LOCATION, CONSTRUCTION AND BETTERMENT SURVEYS

RAILROAD location comprises three distinct surveys, — the reconnaissance, the preliminary survey, and the location survey.

The reconnaissance survey is a more or less superficial, but none the less careful examination of the possible routes between proposed termini, for the purpose of finding the best general route and for obtaining such approximate estimates of cost of construction and operation and amount of probable revenue as may be needed to aid in determining the whole broad question of whether or not to build at all. In the case of a long and important line a subsequent more detailed reconnaissance will serve as a basis for the preliminary survey.

The preliminary survey consists in placing a series of straight lines along the selected route, and by angle and distance measure. ments and leveling, securing detailed information in the form of notes or maps for planning the final line to be built.

The location survey consists in placing the plan on the ground and securing the necessary data for fixing the grades.

Thus it may be said that the reconnaissance determines the general route, the preliminary survey furnishes the data for planning the definite line, and the location survey marks this line on the ground.

The whole operation of railroad location is the securing of data for the design of the road, the making of this design, and marking it on the ground. It is the most important, the most difficult, and the most interesting branch of railroad engineering. It can be done after a fashion with the least technical knowledge of any branch of railroad engineering, and hence has not always

been properly valued or performed. When the student has read the three following chapters on Reconnaissance, Preliminary, and Location Surveys, he should read the paper by Professor Taylor on the "Location of the Knoxville, La Follette and Jellico Railroad," which has been placed in its entirety in the Appendix of this book as the most satisfactory discussion of the correct principles of railroad location applied to a particular case that has come to the author's attention.

Books to be read in connection with Part III are, Wellington's "Economic Theory of Railway Location," Beahan's "Field Practice of Railway Location," and Lavis's "Railway Location Surveys and Estimates."

CHAPTER XVIII

RECONNAISSANCE

The Survey

Three Classes. — The reconnaissance is the first of the series of surveys constituting railroad location. Its character depends very much on the length of line and the territory within which the line lies.

Three classes of work will be considered: 1. A short branch line of 10 to 20 miles through an inhabited civilized territory. 2. A line of 100 or more miles through similar country. 3. A very long line of several hundred miles through wild or semi-barbarous territory without reliable maps.

In any case the best map obtainable is the first requisite, and the ability to read the map must be acquired.

Maps and their Interpretation. — Practically all engineers can read contour maps, but in America only a limited portion of the country has been mapped in this way. The territory most interesting geologically and mineralogically has been mapped by the United States Geological Survey. This includes a larger portion of the eastern and western United States than of the central valley States. Where such maps are available they are the best to use, and are obtainable from the Director of the Survey in Washington at 5 cents a sheet. A sheet covers about 220 square miles. The scale is about 1 inch to the mile, and the contours are usually with 20-foot intervals.

After these, the next best maps for the locator's use are a series of county maps, usually available either as wall maps or atlas sheets. These are to various scales. If such maps are not available, and the territory is within what has constituted the public domain, and has been subdivided by the Government, copies of

the original plats made on a scale of 1 inch to the mile are the best maps for use. They are often very inaccurate, and must be corrected from observations along the route. The copies may be made on sheets covering one township each. The sheets may be obtained with the section lines printed on them. Copies may be obtained from the various general land offices, or from Washington. For new country such maps as may have been made by explorers and published in general atlases are the best available.

The contour map shows readily enough what the possibilities may be. One or more routes joining the proposed termini may be selected as the most feasible of the routes of reasonable directness. The probable ruling grade may be approximately determined in ordinary country from such maps, the distance and probable amount of curvature may be known with some degree of accuracy, but the character of the material is not shown, nor the minor irregularities. A horseback trip, or possibly a trip with a team, with short excursions from the road on foot or horseback at various points, will sufficiently determine the characters of the routes so that a choice may be made from the map.

For reading a map without contours the following suggestions will be helpful: —

1. A main ridge may be traced by following along between the heads of streams of adjoining main watersheds.

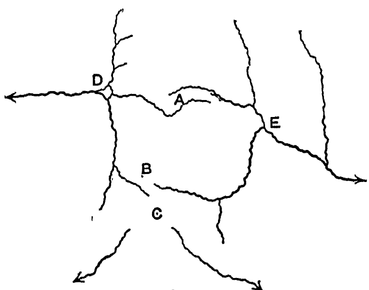


Fig. 84

2. Some sort of ridge or point will lie between the more or less parallel adjacent streams of the same watershed.

3. Two streams of different watersheds, that run nearly parallel and close together, are likely to have a high narrow ridge between them with low saddles or passes. Such an arrangement of streams as is shown in Fig. 84 indicates the likelihood of a low pass at A, and another, possibly higher, actually nearly the same level, though narrower and easier of approach at B in the case this sketch rep-

resents. At C a high hill is indicated by the several radiating streams, and at D the probability of a larger, more or less level, area almost surrounded by hills.

In Fig. 85 the valley has probably gentler slopes on its left (going with the stream) than on its right, and the ridges RR are steeper to the right, facing the figure. These facts are indicated by the larger tributaries in the valley on its left side. The

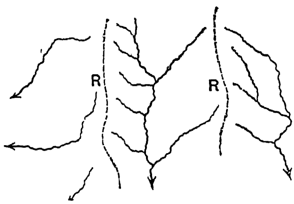


Fig. 85

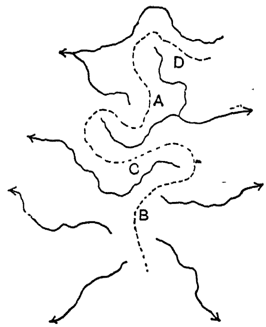


Fig. 86

ridge line shown between the overlapping streams of Fig. 86 is probably very crooked, and with considerable variation of level between such high points as are probably at A and B, and such a low point as is probably at C. One would not seek to follow such a ridge with a line, and in crossing it one would look for a short tunnel at D or C. A very good line might be obtained in the general direction of the ridge by skirting the high points and passing through the low points or saddles.

A stream whose general course is quite straight when mapped at a scale of 1 mile to the inch, has probably a rapid fall and fairly steep slopes on either side. If the stream is very crooked with long radius curves, sometimes doubling back and seeming to run almost up stream for a distance, the stream slope is probably very flat, and the stream lies in a flat, alluvial valley, whose width is probably considerably greater than the extreme width of the stream windings. But if a stream has fairly straight reaches with sharp bends at intervals, it is probably running from bend to bend alongside fairly steep bluffs or hillsides.

In following the principal valley lines of the Mississippi Valley States, one must generally keep some distance from the stream, well up above the first bluff level of the gullies these streams have hollowed out for themselves. These immediate valleys are apt to be low, liable to flood, and very tortuous.

Reconnaissance of Short Line.—With the best map obtainable the engineer will go over the one or more routes that seem possible or probable, will note on which side of the streams followed the line is to lie at various points, where it shall cross those streams, about how many cubic yards of material per mile must be moved in the grading, what structures must be built, number and approximate size, and about what maximum grade may be obtained. From his notes he can estimate what the line will cost within 5 or 10 per cent either way. He determines the cubic yards of grading by judging from experience that it will be about like some stretch of constructed road with which he is familiar. If he is lacking in such knowledge, he may make his estimate by judging that the excavation or embankment, whichever is likely to be in excess, will average some depth, and computing the cubic yards per mile for this depth, estimating that some percentage will be rock. In making such an estimate the engineer must form some notion of where along the route selected the grade line will be. The inexperienced engineer will be likely to put the grade line too close to the ground over long level stretches of prairie. To be sure of drainage in wet times an embankment should be not less than 2 feet high over such stretches, and more if the prairie is a wet one. At stream crossings the subgrade level should be not less than 5 feet above high water. Often the topography will compel more than this, but where it does not, this limit should be observed. In crossing over a divide from one stream to another, the depth of the summit cut will depend on the rate of grade of approach and the distance that grade can be carried. It is better not to hang a line on a side hill when it can be avoided, the best place to lay the line in a valley being usually along the foot of the hills on one side. The depth of summit cut may be approximately determined by running with

a hand level from what is judged to be the foot of the grade to the top of the hill, or by using an aneroid barometer. If the distance is not too long, the hand level is the better. If the territory is open so that long sights may be had, an Abney level and clinometer set approximately at the grade line will do very well, though the angle cannot be determined with great precision.

Often with such a line as is under consideration no separate reconnaissance of the route is made, but a reconnaissance is made when the preliminary survey is undertaken, keeping a day or two ahead of the preliminary. Notes of where to run the preliminary line will be made for the locating assistant directing the detail operations of the preliminary party. These notes are preferably sketches not drawn to scale, but showing the location of the proposed line with reference to natural or artificial objects, such as lone or particularly prominent trees, hills, houses, etc. It is better, in the author's judgment, to make a complete reconnaissance of even a very short line, that the engineer may be certain he has laid his line along the best route; whether he fits the ground well, — that is, runs a good line, — is of less importance than the selection of the best route. In the reconnaissance he should examine every possible route leading in the general direction of the line from his starting-point, should carry his observation of these lines as far as they may reach laterally within a belt beyond which it seems undesirable to go. A sketch map of the entire reconnaissance should be made, preferably on an existing map drawn to large scale, say 1 mile to the inch. For the determination of directions in the field the pocket prismatic compass is the most convenient instrument. A course may be determined on a map by drawing the line and computing its bearing from the measured latitude and longitude differences for an assumed length, say 1000 feet, or 1 mile, or more, if convenient. The helps that may be useful on such a survey are maps, aneroid barometer, hand level or clinometer, pocket prismatic compass, and book of tables. Climbing irons or creepers may be useful at times.

Reconnaissance of Moderately Long Line. — For a line of 100 or more miles, in a settled country, the reconnaissance may be made by one man in much the same way as that for a shorter line. The possible lateral deviation is now greater, and the belt of territory to be examined correspondingly wider. There may be many summits and valleys if the line is crossing the main drainage systems. Mr. Wellington * makes the point, which cannot be too strongly impressed upon the reconnoitering engineer, that the reconnaissance must be of an area and not of a line, and he suggests this method: Imagine a circumference of some assumed radius — say, 5 miles, 10 miles, or 15 miles — drawn with the starting-point as a center. Examine every possible route leading at all in the general direction the survey is to take, to the limit of the circle. Then imagine a concentric circumference with perhaps twice the radius, and follow the possibilities already examined to the limit of that circle, eventually when some approximately middle distance is reached, changing the center to the final point of the line and reducing the radius. It is also well to go over the territory in both directions, for a route that does not suggest itself from one direction may appear very feasible when examined from the other direction. The engineer should learn to attach not too much importance to heavy and difficult work in one place if the remainder of the line involving this heavy work is particularly favorable.

If the country is somewhat wild and mountainous, and particularly if it is timbered, a succession of guides familiar with the ground is desirable. Travel should be on horseback, full notes should be taken, and on a long and difficult line an assistant who is to be second in command of a following locating party should accompany the engineer.

The reconnoitering engineer should note for each of the routes examined: —

1. The character of the territory, probable resources in timber, mineral, agricultural, and manufactured products, making some

* "The Economic Theory of Railway Location."

sort of estimate from his knowledge of roads elsewhere of the approximate business to be immediately developed and the future possibilities.

2. The probable ruling grade that may be obtained, the length of the line, approximate rise and fall of the several classes, total amount of curvature with probable minimum radius, and relative operating value consequent upon these characteristics.

3. The probable amount of earthwork and its classification into earth, and loose and solid rock; possible timber and rock supplies for ties and structures; value of the land; number and length of more important bridges; and consequent probable cost of construction.

Reconnaissance of Long Line.— For reconnaissance of a long line through unknown territory, peopled by semi-barbarians, a considerable party is required for safety and to maintain a camp. Often several parties explore for a considerable distance on either side of a central camp. A very excellent method is to run a central line by transit and stadia along one selected route, getting a string of distances and elevations that will determine quite accurately the length of line, probable ruling grades, amount of rise and fall and curvature; and to explore other routes within the limiting belt, comparing them by judgment aided by barometer, hand level, and prismatic compass, with the stadia route. This method was used by American engineers on a 600-mile preliminary reconnaissance in China, in this instance latitude being occasionally determined by a solar attachment to the transit.

The items to be noted are the same as in the second case.

A complete camp outfit is required for whatever size of party is deemed necessary; and if the territory is tropical, or is known to be unhealthful, or is densely populated with such a population, for instance, as that of China and the Far East, sterilizing apparatus for sterilizing the water used by the party should be a part of the equipment. No other than sterilized water should be used, a supply for use during the day being carried from camp.* The

* For full equipment for surveys in tropical countries see "Railroad Location Surveys and Estimates," by F. Lavis.

instrumental outfit needed will be that usual to the shorter reconnaissance, and in addition a transit and stadia rods. All important instrumental equipment should be in duplicate to provide for accidents. A star finder and a nautical almanac will be indispensable if latitude or longitude is to be determined, and a chronometer or high-grade watch with a known rate.

Importance of Reconnaissance. — A reconnaissance survey is not an elementary operation in railroad engineering. It is the most important part of railroad location which is perhaps the most important item of railroad engineering. Mistakes of grade fixing and alignment, the details of location, can be remedied, — often, to be sure, at great cost; mistakes of construction, too light or too heavy work, track and structures, will eventually be corrected; and mistakes of management and operation may be overcome by a new policy; but a mistake in selecting the route of a road, if not discovered and rectified before construction, is likely not to be rectified for many years, and is certain sooner or later to put the line at a disadvantage with its competitors, if the mistake is not serious enough to permanently handicap the operation from the start, by reason of excessive distance, excessive curvature, or, what is more serious, an excessive ruling grade, and, what is most serious, loss of business from a location that inadequately serves the present and potential traffic centers, or misses some important ones altogether.

Comparing Routes. — The reconnoitering engineer should value his routes first in the order of the probable traffic, second in the order of ruling grade, and last in the order of the minor matters of distance, rise and fall, and curvature. It is probably entirely correct to say as a general proposition subject to variation in special cases, that local business is more valuable than through business; and while commercial conditions are constantly changing, still it will probably always be true that the local business originating and terminating on one line is its most valuable asset. The line that illy serves the larger centers along its general route will always be at a disadvantage, for the rate that the traffic will bear is the rate from the "door of the consignor to the door of

the consignee" * and if the cartage rate at one or both ends be high, the rail rate must be correspondingly low, or the railroad must pay the cartage by maintaining expensive sidings or otherwise.†

Report. — The report of the reconnaissance will state that the most feasible route is —— (described from point to point); the ruling grade is *a* per cent, the rise and fall about *b* feet, the curvature about *c* degrees, the minimum radius being *d* feet. There are special structures —— (described as to locality and character). Tributary to the line there are *e* acres or square miles of grain land, located —— (where along the line); *f* acres or square miles of timber —— (where along the line), being —— (white pine, white oak, etc.), and running *g* board feet to the acre; there are coal fields at ——, bidding fair to yield —— tons annually at once. There are —— special extensive manufactures at ——. There are the following towns and populations, and a tributary rural population of —— per mile of line. The total population per mile of line is ——. The total estimated immediate annual tonnage is

tons products of agriculture
tons products of animals
tons manufactures
tons mineral products

The total estimated annual revenue is	$	
The total estimated operating expense is	$	
The line will cost about $ per mile, or	$	total.

The estimate of cost is judged to be within —— per cent of the truth. The line will require —— months or years to build. —— miles from —— to —— may be in operation within —— months or weeks.

There is no better route between —— and —— than that recommended.

* A. M. Wellington, "Economic Theory of Railway Location."

† It may come about within the not distant future that the railroad will collect and deliver all package freight as is done in some foreign countries, when the advantage of convenient terminals will be more apparent.

THE ESTIMATES

The Traffic Estimate. — In estimating the amount of traffic by various routes, the following rule may be used if the traffic is of the same general class: —

The amount of traffic varies with the square of the population served.

This rule, first theoretically developed by Mr. Wellington,* is proved by a diagram of actual conditions by Mr. Willard Beahan.†

The character of the population and its industries must be considered in estimating traffic. The acreage of tillable land served better than any competitor serves or is likely to serve it, together with the character of crops grown and amount an acre will produce, will determine the agricultural tonnage; the extent of manufactures, the tonnage of this class of goods; and the mining industry, the tonnage of mineral. The relative rates on these classes must be considered, the rate on minerals and grain being usually low, the rates on live stock and manufactured articles high. A reference to the Interstate Commerce Commission Statistical Reports will show the relative quantities of various classes of freight moved in the different divisions into which the United States has been divided for this purpose. The division is not a particularly good one.

The annual expenditure for railway service in the United States is about $23.70 per capita, of which about $17 is for freight service and $6.70 for passenger service, and the total is somewhat rapidly increasing. Detail information concerning the revenue of some road situated as nearly as may be as is the line to be built, should be secured for estimating. It may sometimes be had through the reports of State Railroad Commissioners, but more generally must be obtained from the annual report of the company. When this annual report does not contain the matter in sufficient detail, if nothing better is available, estimates must be made from such generalized information as may be had. The probable immediate (within five years) traffic is a better basis for comparing the values

* "Economic Theory of Railway Location."

† "The Field Practice of Railway Location."

of two lines and for judging the economy of reduced curvature, rise and fall, and ruling grade, than is an estimated future traffic.

Following is a statement of earnings of railroads per mile of line operated in the United States, as given in the Interstate Commerce Commission's Report for 1905.

Item	1905	1904	1903	1902	1901	Average
Gross earnings from operation	9,598	9,306	9,258	8,625	8,123	8,982
Less operating expenses	6,409	6,308	6,125	5,577	5,269	5,938
Income from operation	3,189	2,998	3,133	3,048	2,854	3,044
Income from other sources	1,068	1,003	1,002	981	919	995
Total income	4,257	4,001	4,135	4,029	3,773	4,039
Total deductions from income	2,750	2,688	2,692	2,629	2,528	2,657
Net income	1,507	1,313	1,443	1,400	1,245	1,382

The gross earnings per mile of line in Group II of the Interstate Commerce Commission's subdivision of the United States are larger than those of any other group, being $20,752 in the year ending June 30, 1905, with net earnings of $3,710 per mile. The earnings of Group IV are the smallest, being $5,588 gross and $17 net, for the same year.

Certain typical lines lying in more than one group of states have gross earnings per mile from operation as follows: —

New York Central and Hudson River Railroad	$22,736
Seaboard Air Line	5,216
Illinois Central Railroad	11,323
Great Northern Railway	7,866
Atchison, Topeka and Santa Fe Railway	8,227
Union Pacific Railroad	11,903

The Estimate of Cost. — The estimate of cost is made either by comparing the routes examined with roads of like topography and conditions whose costs are known, or by estimating the yardage for the various sections and its classification, computing the cost at some assumed price per yard, and adding the estimated cost of bridges, culverts, track, buildings, equipment, etc.

It is difficult to tell what the yardage will run if one has had no

experience. To form some idea, the road-bed width and slopes must be assumed and some sort of guess made of the probable depth of filling or cutting while looking at the ground.

The author regards 14 feet for embankment and 20 feet for excavation, including side ditches, as minimum widths at sub-grade for light-traffic, single-track roads, to be subsequently increased to 20 feet and 32 feet respectively, when the traffic shall warrant, and to be so built in the beginning if a large immediate traffic is assured.

Solid rock excavations may be taken out 20 feet wide at first, but 24 feet is better. They are not infrequently made as narrow as 18 feet for new work.

No earth slopes should be less than $1\frac{1}{2}$ horizontal to 1 vertical. Rock may be placed in embankments with slopes of 1 to 1, and rock excavation may be taken out with slopes of $\frac{1}{4}$ horizontal to 1 vertical. Including ditching, road crossings, etc., excavation and embankment of various base widths, and with slopes of $1\frac{1}{2}$ horizontal to 1 vertical may be expected to average about as in Table 11. If the line is approximately half cutting and half filling, the total yardage will be half the tabular quantities if there is no waste or borrow; that is, if the embankments are made from the excavations, with no waste.

If it be estimated that the excavation is in excess, the total yardage is obtained by taking that fraction of the tabular quantity that the total length of cut is of a mile; if it be estimated that the embankment is in excess, the method is the same, using the length of embankment.

Earthwork should be estimated at what it will probably cost in the locality. Average figures may be 25 to 30 cents a cubic yard for earth, 75 to 90 cents for loose rock, and $1 to $1.50 for solid rock. These are not costs but contractor's prices.

Clearing and Grubbing the right of way may be estimated at $50 per acre for ordinary timbered country, and as high as $400 to $500 an acre for the heavy timber of the northwest United States. The better unit is the square of 10,000 square feet, which may be estimated at $12.50 for ordinary timber.

Table 11

For Reconnaissance Estimates

Approximate cubic yards of embankment per mile for various widths of road-bed at subgrade, and depths to 15 feet, including an allowance for road crossings, etc. For excavation add 3000 cubic yards to the tabular quantities for ditching, etc. The side slopes are 1 on $1\frac{1}{2}$.

Depth of fill or cut	Road-bed Widths							
	14	16	18	20	24	26	28	32
1	3,100	3,500	3,900	4,300	5,100	5,400	5,800	6,200
2	6,700	7,500	8,300	9,100	10,600	11,400	12,200	13,000
3	10,900	12,100	13,300	14,500	16,800	18,000	19,200	20,400
4	15,700	17,300	18,900	21,000	23,600	25,200	26,700	28,300
5	21,100	23,100	25,000	27,000	31,000	32,900	34,900	36,800
6	27,100	29,500	31,800	34,200	38,900	41,300	43,600	46,000
7	33,700	36,400	39,200	41,900	47,400	50,200	52,900	55,700
8	40,800	44,000	47,100	50,300	56,600	59,700	62,800	66,000
9	48,600	52,100	55,700	59,200	66,300	69,800	73,300	76,900
10	56,900	60,900	64,800	68,700	76,600	80,500	84,400	88,300
11	66,000	70,200	74,500	78,900	87,500	91,800	96,100	100,400
12	75,400	80,100	84,800	89,500	99,000	103,700	108,400	113,100
13	85,500	90,600	95,700	100,900	111,000	116,100	121,200	126,300
14	96,200	101,700	107,200	112,700	123,700	127,600	134,700	140,200
15	107,500	113,400	119,300	125,100	136,900	142,800	148,800	154,600

Short Tunnels through rocky points may be estimated at rock excavation prices for the volume removed. Long tunnels through earth requiring timbering or masonry lining, or through rock, require special estimates. If less than a mile long, the excavation may be taken for rough estimates at six times the cost of similar excavation in open cut, and the lining, if required, at \$50 per linear foot for concrete or concrete side walls and brick arches. The section of a single-track tunnel will run about $12\frac{1}{2}$ cubic yards per linear foot if unlined, and from 15 to 20 cubic yards if it is to be lined. Special difficulty with water may run tunnel costs up to \$200 per linear foot or more.

Bridging will be estimated for each crossing, from notes of the character of foundation, and the width and the height of abutments and piers, remembering that the track should be at least 5 feet above high water. The weight of steel will be estimated from the formulas of Chapter VI. The volume of masonry will be estimated from rough sketches that may be made for piers and abutments, and the probable depth of foundation. Concrete for abutments and piers, and reinforced or armored concrete for arches, is the common modern masonry for ordinary structures. It may cost from $4.50 to $10 or more a cubic yard, according to the cost of materials and the difficulty of foundations. An estimate of the length of haul for materials from quarry and nearest railroad station, with the cost at these points, must determine the cost of the concrete. Special structures, such as bridges across large rivers like the Mississippi or Missouri, with difficult foundation work, require special estimates. The Memphis bridge may be mentioned as an example. The pier masonry (stone) cost about $75 per cubic yard, including the cost of foundations, which was nearly two thirds of the whole.

Ordinary 16-foot stringer openings through embankments not more than 10 feet high may be roughly estimated at $500 each if there be no difficult foundation work.

Wooden Trestles may be estimated at from $9 to $10 per linear foot of track for trestles 15 feet high, with 25 cents per linear foot for each additional foot of height if timber costs $50 per 1000 feet in place. Very high trestles requiring special design may cost slightly more. Up to from 20 to 30 feet high it is usually cheaper to build embankment than trestle, the particular height depending on the cost of earthwork and timber. It is always better, if reasonably cheap, to build a culvert and bank than an opening of any kind, even if the culvert must be of wood. The track is safer. Modern construction through hilly country frequently includes embankments over 100 feet high.

Stone Box Culverts are rarely built, concrete or iron pipe taking their place. These small culverts may average 1½ to the mile. Their length will depend on the height of the bank over them,

Pipe culverts may be estimated about as in the following table, except when definite data are at hand.

TABLE 12

APPROXIMATE ESTIMATING COST OF CULVERTS.

Concrete at $5 to $10 a cubic yard in place. Iron pipe at 1 cent a pound delivered.

Diameter of pipe — inches	Cu. yds. in two head walls	Cost of barrel per foot in place		Cost of two head walls
		Iron pipe	Concrete	
12	2	$1.50	$0.50 to $1.00	$10.00 to $20.00
18	2.5	2.00	1.00 to 2.00	12.50 to 25.00
24	4	2.75	1.25 to 2.50	20.00 to 40.00
30	6	3.20	2.25 to 4.50	30.00 to 60.00
36	8	{ 4.60 6.50*	2.75 to 5.50	40.00 to 80.00
48	12	{ 6.25 8.75*	6.50 to 13.00	60.00 to 120.00

* The larger prices for the cast-iron pipe are for heavy pipe under high embankments.

Track must be estimated by its length, the weight of rail used, market prices of rails and fastenings, probable cost of ties and from $250 to $300 per mile for track laying. Some track laying costs more than this, and it is sometimes estimated at as much as $600 a mile.

Ballast, if of broken stone, may cost $1 per cubic yard in place, and there may be from 1500 to 3000 cubic yards to the mile. Gravel ballast may cost from 20 to 40 cents a cubic yard in place, according to the length of haul and the freedom of the line for hauling. Costs both sides of these limits are not uncommon. If the average haul is not more than 15 miles, and there be not more than a train an hour to interfere with the work train, 25 cents may be used for a rough estimate. This means excavation with steam shovel, and unloading with an unloader or dump cars.

Road Crossings, if any, may be estimated at $25 per mile, but it must be remembered that each one is an element of danger,

and consequent weakness, and none should be permitted that can be avoided at any reasonable expense.

Cattle Guards, required only at country road crossings, may be estimated at $25 each, or $50 per mile.

Track and Yard Signs may be estimated at $10 per mile of road.

Side Track and Yards constitute from 15 to 25 per cent of the main line mileage. Perhaps 15 per cent is enough to estimate for new construction. This track will usually be light grading and cheap ties; but in new work about the same rail as the main line, though a lighter rail may be used with economy, except on passing sidings taken at some speed. If side-track and yard grading be estimated at 4000 cubic yards to the mile, ties 2640 to the mile, and the additional mileage be taken at 20 per cent, probably full allowance will be made for switches and frogs, drainage, crossings, etc.

Fencing may be estimated at $300 per mile of road fenced. It may sometimes run a third higher. The estimate is for a good nine-strand woven wire fence, without barbs. A barbed fence should never be used.

Telegraph expense usually includes only that of the labor of constructing telegraph lines, the telegraph company furnishing material and some superintendence. The labor may be estimated at $50 a mile. It will run higher if several wires are to be strung, and may be occasionally less.

Interlocking Plants complete may be estimated at from $250 to $300 per lever — often less — and when a house must be built for less than 8 levers the cost may run up to $600 or $800.

Water Stations including only a column taking water from city mains will cost from $300 to $400 per column in place. A 56,000-gallon tank may cost $1500 and a pump from $400 to $500. A pump house may cost $350. Wells, ponds, etc., are too uncertain for estimate, but water stations as a whole may be estimated at $400 a mile for a fairly busy line, less for a light branch line, more for a heavy traffic line.

Buildings and structures about stations and yards may be estimated as follows: —

Small frame station buildings from 80 cents to $1.25 per square foot, the larger price being for the smallest station of, say, 500 square feet, the smaller price for large stations of, say, 1500 square feet. If the station be two-story, with living rooms, the figures should be from $1.25 to $1.75 per square foot of ground covered.

Good modern brick and stone passenger stations, $3.25 to $4 per square foot, outside dimensions.

For unpretentious brick stations, and one-story brick shop buildings, from $1.50 to $2.50 per square foot, with the higher figure seldom reached except for power stations.

For modern two-story and basement brick buildings, from $7 to $8 per square foot; for three-story buildings, $10 per square foot.

Small frame yard buildings, from 50 cents per square foot for the less important to $1 for the more important.

Section Hands' Dwellings may cost from $1000 to $2000 each.

Brick Engine Houses may cost about $1200 per stall, slightly more for a small house, and slightly less for a large house. A simple single-stall frame house may be built for $500.

Turntables of steel with stone or concrete curbs may cost $3500 to $5000, according to length, and price of materials. A temporary wooden table can be built for $500 or less.

Track Scales may cost from $12 to $15 per ton capacity in place. The capacity should be from 60 to 80 tons. They are built both sides of these limits.

Ash Pits well constructed of stone or concrete and steel, may cost from $1200 to $1500.

Coaling Stations vary so in style that general estimates may not be of much value, but for reconnaissance estimates perhaps $200 to $225 per pocket for automatic chute coaling stations, plus a constant sum of $1000 more or less for approaching track, may be used.

Right of Way may be averaged at 100 feet wide plus about ½ acre per mile of main line for stations, terminals, and yards.

The estimated price should be about twice the market price for the land through which the line runs. Estimates for large terminals in great cities, often costing in the millions of dollars, must be the result of careful special study.

Equipment may be estimated by comparing the equipment of other lines doing about the business expected of the proposed line. Its cost averages about $3500 per mile of single track in the United States, varying from very little to $20,000 more or less for heavy traffic Eastern roads with considerable floating or marine equipment. For the average roads of the central United States the cost is from $2000 to $5000 per mile.

Engineering may cost from $400 to $500 per mile of constructed road, more for heavy, high-grade construction. The location will cost from $50 to $150 per mile of completed location for all surveys necessary. The smaller price is for open, easy country, the larger price for wooded and difficult country. The cost, under especially favorable or unfavorable conditions, may lie on either side of these limits.

Legal and General Expenses of Organization and management during construction may cost from a quarter to three fourths the cost of engineering.

Interest may amount to as much as 10 per cent of the cost of construction.

A Complete Estimate for what may be called an average line through a rolling country with little rock, fairly well settled, connecting moderately large cities follows. The rail used is 80 pounds to the yard.

TABLE 13

AVERAGE COST OF A MILE OF AMERICAN RAILROAD

Right of way	$1,800
Terminal stations, land, etc.	4,000
Grading 20,000 yards earth at 30 cents	6,000
2,000 yards rock at $1.25	2,500
Bridges and culverts	2,000

TABLE 13 — *Continued*

Track:	Ties at 50 cents delivered	1,350	
	Rails, 126 tons at $30 delivered	3,780	
	Joint bars, 20,500 pounds at 1.8 cents delivered	369	
	Bolts and locks, 2,560 pounds at 2.7 cents delivered	70	
	Spikes, 6,000 pounds at 2.3 cents delivered	138	
	Track laying	300	
	Total track	6,007	6,000
Sidings and yards, distributed proportion			1,000
Ballast, gravel 2,000 cubic yards at 25 cents			500
Fencing			300
Telegraph			150
Water supply			400
Stations, ordinary, and section houses			500
Roundhouses and terminal buildings, shops, etc			750
Equipment			3,000
Engineering			1,000
Legal and general			300
Interest			3,020
Total			$33,220

To this must be added for interlocking and block signals if these essentials of safe railroading are used, so that the average American railroad should cost about $35,000 a mile fully equipped.

About $20,000 of this estimate is for the permanent way, exclusive of buildings, terminals, etc., but including side track and yards. This portion of the estimate may very readily be much increased by excessive bridging, deep cuts, much rock work, many crossings avoided by underhead or overhead structures, etc.

Recent examples of construction in Pennsylvania exceeding the figures of this estimate by from 50 to 300 per cent have been cited,* and expensive terminals in large cities would greatly increase the item of their distributed cost.

* *Railroad Gazette*, September 19, 1906, *et seq.* A series of valuable articles.

CHAPTER XIX

PRELIMINARY SURVEY

General Methods. — There are two general methods of making a preliminary survey for a railroad, the use of the one or the other depending on the object of the survey. One locating engineer will be of the opinion that the preliminary survey is to be a series of straight lines the longest of which are to be, possibly slightly altered in position, the final tangents of the located line, to be connected with such curves as may be possible or necessary. Another understands the preliminary survey to be made for the purpose of obtaining a narrow belt of topography, within which the final line will probably lie, on the map of which he may plan a final location to be reproduced on the ground with such slight alterations as the further study may suggest or discovered discrepancies make necessary. The former method was the old method, and is still applicable in a measure in easy country when there seems to be but one place to lay the line; but in country of any difficulty whatever, there can be no question but that any engineer can better fit the ground with less curvature if he can look down upon a long stretch of line at once, as he does when he looks at a contour map, than if he must fit the line by trial, totally unable to see when two or three miles of line are behind him, what betterments he could have made in the line ahead by slight changes in the line behind. It is not uncommon for engineers to say that the good locating engineer must carry his line in his mind so that he can see just what effect a change at one point will have on the line either side of it; but while the experienced engineer who has a natural aptitude may have gained some ability in this direction, the young engineer has none, and no engineer has so much that he cannot see such effects better on a map. But it is true that changes in detail can best be studied

on the ground *with* the map, and a knowledge of the character of the ground is essential to a wise location. The author therefore advises a belt of topography mapped to a scale depending on the ruggedness and irregularity of the line, omitted where the line lies across long fairly level stretches, where considerable lateral changes would not much affect the profile, but taken with considerable precision on those portions where lateral changes would in any considerable degree alter the profile.

The preliminary survey, therefore, like a reconnaissance, should be of an area and not merely a line, though the area is narrower and more definitely mapped.

The first method, then, consists in laying out a line as nearly as the engineer can judge where the final line will lie, marking the line by stakes at such intervals, usually 100 or 200 feet, as may seem wise, turning such angles as may be necessary, taking the elevations of the ground along the line at the stakes set and such other points as may be deemed wise, making a profile and map of the surveyed line, and from these and a knowledge of the material, an estimate of cost known as the preliminary estimate. At each stake a cross slope will be taken, or topography may be sketched in a note-book with notes at intervals that the line should be so many feet to the right or left, giving such a variation in the profile.

The second method is like the first, except in the matter of topography. In this method the line is mapped, the elevations of the stations written on, and the map — made on sheets — is taken into the field by a topography party of usually three men, who with tape and hand level take measurements from which contours, usually with 5-foot intervals, are plotted for a distance either side of the line that will surely include the final location which is plotted on this map without much reference to the original line except at critical points.

For this second method the transit and stadia may be used to advantage. In ordinary country a stadia contour survey can be made and mapped in much less time with much less force than the ordinary line and level survey. It does not furnish a profile of

any line that may be drawn on the map so closely correct as one obtained by line and level, but it does furnish a profile likely to be as near the final location profile as is the preliminary line and level profile. But the chief use of the stadia on railroad surveys is for what may be called instrumental reconnaissance of difficult sections just ahead of the preliminary survey, and for the purpose of determining with about what maximum grade to start up or down a hill, what particular branch of a stream to take, etc., and, again, it is by far the most feasible method of work in planning long development* on high mountain divides.

The Party. — For the second method without the stadia, a full preliminary party for a long line will consist of

Chief of party
Assistant who usually is transitman
Two chainmen
One stakeman
One flagman
Two or more axmen, according to the character of the country
One levelman or leveler
One rodman — sometimes two in open rolling country
One topographer
Two assistants
One draftsman
One cook
Three teamsters and teams
A saddle horse.

In a settled country where living at farmhouses or country hotels can be counted on, the cook is unnecessary, and not more than one teamster is absolutely essential. But a camp outfit insures independence and usually better food and more comfortable living, and a party that is well kept works well.

* Development means increasing the length of the line over that necessary to go directly over the summit, for the sole purpose of gaining the distance necessary to reduce the rate of grade.

General Duties of the Party. — The chief of party has general control of all movements, selects the route for the survey, and directs in a general way the operation of the party.

The assistant, subject to the directions of the chief of party, is in charge of the field work and directs it in detail. He acts as transitman and at night maps the line run during the day. In the absence of the chief of party he is in full control of the party. He should be a man of good height, strong, and active.

The head chainman is in charge of the working party at the front of the line, rear chainman, and axmen; he carries the front end of the chain, sees that the measuring is properly done, that good progress is made when clearing the line is necessary by keeping his flag on line and directing the axmen, and selects new transit points. He usually carries his line flag in and out of camp. He is also responsible for the order of the men's sleeping tent. Like the transitman, he should be a strong, active man.

The rear chainman carries the rear end of the chain, obeys the head chainman's orders as to chaining, and watches the numbering of the stakes to see that no error is made. He sees that the chain and pins are carried to and from camp, and that they are in good condition.

The stakeman carries, marks, and drives the stakes. He may assist the axmen in difficult clearing. Either he or the axmen will make stakes as may be convenient. On the prairies shop-made stakes are used; the stakeman sees that a sufficient supply is in the line wagon each day, and he carries enough to last from one transit point to another, or from one point of access to the wagon to the next. Stakes may be carried in a strap or rope; a basket soon wears out.

The axmen clear the line in timber, assist in carrying stakes over long stretches of open country, assist in moving camp when they can be spared, etc.

The levelman takes the elevations with the level, assisted by the rodman. He plats the profile at night, the rodman calling the elevations.

The rodman carries the rod, a hand ax, round-headed tacks,

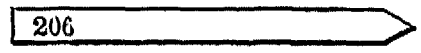
and a note-book. He holds the rod where it should be held, makes bench marks, does such little clearing as may be necessary, makes and drives pegs for turning-points, and keeps a record of all turning-point rod readings in his note-book, which is called the rodman's check book. At night he calls the elevations to the leveler, who makes the profile, and assists in such other office work as may be asked of him. He also notices the numbering of the stakes to see that no errors have been made.

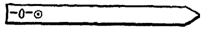
The topographer carries a light drawing board on which are sheets showing the line run the previous day. With the aid of his two assistants who carry a light rod, a hand level, and a metallic tape, he determines and draws contours, streams, fences, buildings, etc., adjacent to the line. If there is no draftsman he may finish up the maps in ink in the office, and do such other drafting as may be necessary. He is subject to the orders of the transitman, and directs the work of his own party. The work in detail will appear.

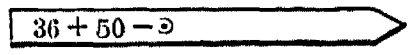
The flagman holds the line flag on the station last occupied by the transit, and he is known as the back flagman.

The boss teamster, who may also be the commissary, attends to the furnishing of camp supplies, to the loading and unloading of the camp outfit, and the establishing of camps. He also directs the other teamsters, seeing that their wagons and teams are kept in condition, and cares for the saddlehorse. One or more teams usually take the party to work in the morning, one wagon, the line wagon, remaining with the party during the day, carrying the lunch, stakes, and surplus clothing. The driver of the line wagon brings the lunch to the noon resting-place and has it ready to eat when the party stops work.

Stakes and Stations. — Transit points are marked by hubs of 2 by 2 inch oak or other hard wood, 15 inches long, or in timber country by equivalent hard-wood hubs cut by the axmen, centered for the transit plumb bob with special surveyor's tacks having flat indented heads. Stakes to mark station points are of $\frac{7}{8}$ by 2 inch pine, dressed on both sides, 20 inches long, or, again, in timbered country equivalent hard-wood stakes made by the axmen

and blazed at the top for marking. The stakes are marked from the top down, thus 

A station is 100 feet of distance, and the term is used indiscriminately to mean this distance or the stake point that marks its forward end with its number. The context usually indicates whether the 100 feet or the stake point is meant. The initial point of the survey is called zero, the stake marked 

. The number on any stake should indicate the distance in stations of 100 feet from the beginning to the station. The transit hub is driven to within about a half inch of the surface of the ground, and on the left (some engineers use the right) about a foot away a guard stake — ordinary station stake — is driven, numbered with the station of the transit point, and a circle with a dot in the center to indicate a transit point thus. 

The numbering should face the hub, and the stake should be slightly inclined top toward the hub. The inclination should not be sufficient to prevent easy reading of the number on the stake. Station stakes are set as often as may be required, usually either at the end of each 100 feet, or every two stations. Sometimes in flat prairie one each fifth station is used. The stakes face the beginning of the line, and are driven plumb and deep enough to stand firmly.

Chaining. — The chaining should be well done, much better than is usual, in order that time may be saved on the following location. The location is determined from the information given by the preliminary survey; and if that information is incorrect — there almost always are some errors — costly waits result while the change in location necessitated by the error is being computed.

Each chainman should carry a hand level and plumb bob in leather pouches attached to a belt. In chaining on sloping ground the hand level should be used by the lower man to determine the length of chain that can be held level and the height to hold it. The plumb bob should always be used by the lower man when breaking chain, and in some cases where it is impossible to hold either end on the ground because of brush or other obstructions, bobs should be used at both ends. It is well to remember

that where subsequent work depends on preliminary work, speed is made by going slow. It is said that a famous capitalist was accustomed to say to his assistants in time of stress, "Go slow, boys, I'm in a hurry."

The chaining should be to pins set a few inches one side of the line, just far enough not to be disturbed by the driving of the stake.

If a chain is used, there should be two chains carried, one of which remains in camp to be used as a standard. The line chain should have a flat link at one end, between the last wire link and the handle, and the zero of the chain should be filed on this flat link each morning, being found by comparison with the camp standard. The chain will gradually lengthen in the course of a long survey, and a uniform length may thus be kept.

Angle Work. — Angles at all changes of line should be read to minutes, and the compass should be read and recorded at each setting of the instrument whether an angle is turned or not. Whether to run by deflection angles, the usual American method, or by azimuths, is a matter for decision. The usual method is to sight the last point occupied, — "take a back sight" — with the transit reading zero and using the lower motion of the transit, transit the telescope, turn in the new direction with the upper motion, and read the angle, which is called the deflection angle. Errors of adjustment of the line of collimation appear in the angle unless the instrument is again turned on the back sight, the operation repeated with the telescope inverted, and the mean of the two angles recorded. In producing a straight line this method of double centering, as it is called, should always be used, the forward transit point being established midway between the two points given. If the instrument is in perfect adjustment, the two forward points will coincide. This is the same operation used for testing the adjustment of the line of collimation.

By the azimuth method the line of collimation is set on the back sight by the lower motion with the vernier reading the back azimuth of the stretch, — that is, the forward azimuth plus 180 degrees. The upper motion is then loosened and the line of

collimation brought to the new direction, when the vernier will read the azimuth of the forward course. This is then recorded.

The back azimuth used should also be recorded for future check. There is no transiting of the telescope, and error of the line of collimation does not affect the angle unless the two vertical angles are quite different. There is perhaps more chance for error in reading angles, since there is the extra reading for the back azimuth, which must also be computed. The deflection angles which are wanted to show the degrees of curvature to be used must be obtained by subtracting successive azimuths instead of being directly given by the notes. For computation of latitude and longitude differences for platting, the azimuth is the better, as it is for checking by the needle. It is simpler for platting by protractor or tangent offsets than the deflection angle method. A considerable experience has convinced the author that the method by azimuths is the better.

For azimuth work the instrument should have two sets of figures on its horizontal circle reading in opposite directions from 0 to 360 degrees, and each inclined in the direction of increasing numbers. It is convenient to have a continuous circle on the compass box, and to start with magnetic north or true north as 0 azimuth. If true north is used there should be a declination movement and vernier, that the compass may read 0 when pointing in 0 azimuth, and the numbering should be counter-clockwise. If an arbitrary line, as the first line of the survey, or the line of an existing road from which the survey starts is to be assumed as 0 azimuth, such a scheme of figuring is not so helpful, and the ordinary quadrant figuring may be used. Both may appear on the circle.

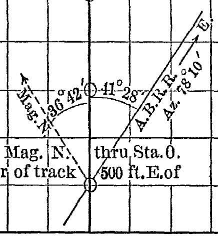
In most parts of the country errors of angle reading of 15 minutes may be detected by the needle; and in any part of the country, no matter how great the local attraction, if needle readings be taken both forward and back at each transit point, this check may be had.

The note-book in which the angles are recorded should be ruled with six columns on the left page, and with a single red line

Station	Azim.	Needle	Defl. Ang.	Back Az.	Needle Back
42	12° 15′	12° 15′	20° 05′ R.	172° 10′	172° 10′
		Distance 2550 ft.			
16+50	352° 10′	352° 05′	44° 32′ L.	216° 42′	216° 45′
		Distance 1650 ft.			
0	36° 42′	36° 45′	41° 28′ L. from A.B.R.R.		

Date, July 1st '07. Begin Sta. 0

Weather, Clear - Warm



Zero azimuth is Mag. N. thru Sta. 0.
Sta. 0. is in center of track 500 ft. E. of mile post 361.

Fig. 87

in the center of the right page, which should be covered with $\frac{1}{4}$-inch section ruling, the horizontal lines corresponding with the horizontal ruling on the left page. The right page should be used for all the transitman's computations, which should be neatly arranged and annotated for future recognition. Computations should not be made in the back of the book or on scraps of paper. The single red line and section ruling are for the occasional sketches the transitman may make, and so that on minor lines such limited topography as may be needed may be sketched in. The arrangement of columns should be as shown in Fig. 87, which also shows a good form for notes.

The distances are written in to serve as check for the scaling used on the map.

It is doubtful if there is a form that can be called common for notes. That indicated gives complete information and furnishes all possible checks. The notes should begin at the bottom and run up the page. The book is $4\frac{1}{2}$ by $7\frac{1}{2}$ inches.

Leveling. — The leveling is done to hundredths of a foot on bench marks and turning-points, and to tenths on stations except transit points, which are taken on the hub to hundredths. The starting-bench mark — called simply bench — is a permanent point of known or assumed elevation. If there be a permanent building near by, a projecting corner of the water table or a corner of a stone step may be used. If there is no building, but the ground is rocky, a permanent point that can be completely described is used. If there are trees near by, a root is cut and a round-headed tack is driven into the pyramidal point that is hewn out. The tree may be blazed and the number of the bench drawn on. Figures are soon obliterated and there is not much to be gained by writing the elevation. If there are no trees, a stout stake is driven to within $\frac{1}{2}$ inch of the surface, rounded somewhat on top and a round-headed tack driven. A guard stake is driven alongside with the number of the bench and, if desired, the elevation marked on it.

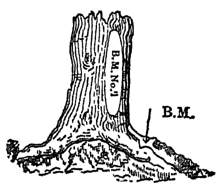


Fig. 88

The benches are established at least 50 feet to one side of the line.

The starting bench being established, the leveling proceeds in the ordinary way, rod readings being taken on the ground beside each stake, on transit hubs, and at points between stakes, if there be any abrupt changes in level. The crossing of a ditch would be noted on the right-hand page of the levelman's note-book, the station and plus, and the width and depth of the ditch being given. At about each half mile benches will be established and their elevations determined. Sights will not, as a rule, be taken more than 300 feet on each side of the level, and distances from plus pegs to instrument should equal distances from instrument to minus pegs to eliminate errors of adjustment. Turning-points are usually pegs made by the rodman and driven when required. Neither the ground nor any small stone should ever be used as a turning-point. Solid, fixed rocks may be used. Turning-points should be described in the rodman's check book so that they may be found again within a reasonable time should it be necessary. When the rodman has gone the full distance permitted or possible, he signals the levelman for a peg by a whirling motion of his hand, which the levelman should answer with the usual all right signal. At the time of giving the signal the rodman should be holding up his rod, — fully extended if he is going down hill, and closed if up hill, — and the levelman before giving the all right answer will look to see that he can see the rod through the instrument; if not he will motion up or down, as the case may be, and the rodman will try a new point.

When rock that is at all likely to be reached by the excavation outcrops, its elevation and station should be noted.

At all stream crossings the levelman and rodman look for high-water marks and get the elevation of such as are indicated. In crossing deep and narrow ravines the rodman may lift the rod alongside his leg or body till the levelman just catches the target at the top, when the rodman notes the distance from the ground to the bottom of the rod, adds it to the full rod and gives the resulting reading to the levelman. The length of the rod for ordi-

nary stations and pluses may be thus increased by 4 or 5 feet. If a still longer rod is needed, the instrument must be pegged down the hill, or a hand level may be used for the few readings that must be gotten before reaching the farther side, where a peg may be established and the work proceed as usual. If no hand level is available, and the slopes are fairly uniform, a turning-point may be set across the ravine and the instrument then pegged down to the bottom, and then moved to the farther side, starting from the peg set there. A bench should be established at the close of each day's work.

Various arrangements of level notes are used, but the author has found none more satisfactory than the ordinary form for profile leveling, having five columns on the left-hand page headed, Station, + S, Inst. — S, Elev. A well-liked form has a sixth column for elevations of turning-points and benches, the use of which is to prevent confusion in making profile, the rodman in calling elevations being likely to call those of the turning-points, which are not plotted, with the others, if they are in the same column. Some levelmen prefer a sixth column for minus sight readings on turning-points.

The leveling instrument should not be too sensitive, a comparatively short bubble, with bubble graduations of an angular value of about 20 seconds, is all that is required. If a reading be taken with such an instrument, when the bubble shows a half division error of level, the reading at 300 feet will be 0.015 feet in error. This indicates the necessity of care in equalizing plus and minus sights. If it is necessary to make one set shorter, as in going down hill, the other set should be made shorter by the same amount at the next opportunity. Intermediate points may be a little in error, but the final points will be correct so far as errors of adjustment and leveling are concerned.

The rod should be the Philadelphia or self-reading rod, read by the levelman at stations and by target on turning-points, the levelman taking the reading here also as a check.

So far as possible the levelman should work out his elevations while the rodman goes from one station to the next. A system

of signals should be arranged between rodman and levelman for calling readings when distance and wind prevent comfortable use of the voice. The rodman gives the levelman minus readings on pegs as the latter passes him to a new position, the levelman looking at the rod to check the reading, and both comparing elevations of pegs, a record of which the rodman keeps in his peg book.

Mapping. — For filing maps in public records, a scale of 1000 feet to the inch is good. The law sometimes prescribes the scale. For office purposes and general reference the scale should be 400 feet to the inch, the same as the profile; and for planning location in anything more difficult than open prairie the scale should be 100 feet to the inch, so that measurements may be made on the map to the nearest foot.

The mapping should be by coordinates, and, for the field working maps, on sheets about 18 by 24 inches, which cut readily from 36-inch paper. Except for its cost, which is not more than the saving in time warrants, accurately printed cross-section paper, which comes in rolls 20 inches wide, does well and saves much time. A better paper would be a similarly printed paper with very fine lines and with squares of 2½ inches for the 400-foot scale, and 5 inches for the 100-foot scale. The absence of the smaller division lines would be an advantage in mapping topography, and the larger rulings would accomplish the purpose of saving time and insuring accuracy in the continuation of the coördinate axes. Sheets could be matched together in only two directions, whereas with plain paper they may be matched in any direction to get the most line on a sheet, but this objection is slight and covers only the small item of more or less paper. Such paper is not now made.

The coordinates of each angle point of the line are computed and plotted from an assumed meridian which is drawn on the first sheet and continued to the next. Along this meridian 1000-foot points are marked and parallels drawn at right angles to the meridian. On these parallels 1000-foot points are marked and auxiliary meridians drawn. The sheets thus have one or more 1000-foot squares, from the corners of which measurements may

always be made within a single 6-inch scale length to the required point. The meridians and parallels are marked with their respective distances from the origin.

The transitman, checked by the draftsman if there be one, computes the coordinates each night for that day's run, plots the points, connects them with straight lines, puts on the stations of the angle points and marks each tenth station, when the sheets are turned over to the topographer who marks lightly the intermediate stations and either lightly pencils in the elevations taken from the levelman's book or makes a separate list of those elevations for use next day. The line is drawn in red. If two or three lines are run at some difficult place, all starting from points on the first line, the first line will be in red, the second in blue, the third in green, etc. They will usually be called the "A" line, "B" line, etc.

Both maps, the office map and field map, and a tracing of the former, should be kept up from day to day, and for this purpose in country of any difficulty the draftsman is needed. The smaller scale map used only in the office may be made on long sheets or even on a roll of paper, not being started for two or three days till the general run of the line is well enough determined so that it may be properly laid on the paper. A line running approximately diagonally with the cardinal points could not be mapped on continuous cross-section paper, and must be mapped on sheets if cross-section paper is used. The tracing may then be on a continuous strip so far as that is possible.

When the topographer has finished any field sheets, if they are not at once needed for planning location, the draftsman transfers the matter drawn by the topographer to the office maps.

The Profile. — The profile is plotted on profile paper, preferably Plate A, which has a horizontal scale of 400 feet to the inch and a vertical scale of 20 feet to the inch. Tracings of the profile may be made on a special thin profile paper printed in red or orange from the same plates, and from which blue-prints can be made.

The profile paper is numbered every tenth station and every

fiftieth foot in elevation, the bottom being assumed at some round number likely to give the largest possible stretch of profile without breaking; that is, running off the top or bottom, and beginning over again by shifting the elevation of the horizontal lines.

The leveler puts a point at the elevation of the o station, the rodman calls the elevation of the next station, the levelman puts his pencil on this point and draws a free-hand, approximately straight line backward to the point fixed for station o. The rodman calls the elevation of station 2, the levelman puts his pencil at this point and draws back to station 1, and so proceeds. When a plus is reached, the levelman estimates the proper point on the paper and draws back to the last point platted. At each tenth station the rodman calls "check." If the levelman's next point is not the tenth station, there has been an error, and it is looked for and corrected. The finest rulings of the paper represent vertical feet, the leveler estimates to tenths. The pencil must be very sharp, but not too hard, about 4 H. All ditches are drawn in and streams are shown, both bottom, water level, and high-water level. When the profile has been penciled in, it is examined by the chief of party, who not infrequently from his memory of the ground discovers errors of 10 feet or more in the vertical platting. When the profile is finally approved, it is inked in in black, and is ready for the grade line that is to be put on by the chief of party. This he does so as to keep under the maximum ruling grade, above high water at stream crossings, sufficiently high above long wet prairies or marshes, and otherwise to make the excavation as little as practicable. He uses a fine black thread, which is stretched along the profile for such distances as seem feasible, equalizing the cuts and fills as nearly as may be by eye. He does not follow the more or less laborious method of location grade fixing to be described hereafter. He then sketches on the profile such changes in it as he thinks it may be possible to secure by moving the line at this point or that, and these serve somewhat to guide the topographer in his subsequent work. The grade line is inked in in red, the elevations written at the points of change of grade rate, and the rate of each stretch in per cent,—that is, rise or fall per 100 feet,

is written along the grade line, as shown in Plate XIV, page 300. If there be supposed to be rock in any of the cuts, its approximate estimated profile is penciled in and marked "probable rock profile."

The Topography. — The topographer carries a light drawing board with an oil or enamel cloth cover forming a pocket on one side, the loose flap covering the free side of the board when not in use. The sheets not in use are carried in the pocket. The topographer's instruments should be carried in a leather or canvas pocket attached to his belt or slung on his shoulder. He needs two small transparent triangles, a flat boxwood scale 6 inches long, eraser, pencils, and pocket compass. His assistants carry hand level, tape, and light self-reading rod. The topographer, from measurements by his assistants, draws in all artificial structures within his limit of width, say 300 feet on either side the line, roads, fences, streams, etc. He also draws the contours at the agreed interval, usually 5 feet, within the required belt. He must use judgment in taking contours. Where the ground is flat and considerable movement of the line will not affect the profile, contours are not required and should not be taken, as the topographer will never move faster than the transit party, and may be slower in rolling, open country. He inquires to find the boundaries of the various land holdings, locates section lines and corners when within reach, and notes the names of owners on his map. He uses the pocket compass to measure the angle of intersection of land lines and preliminary line. A light wooden cross on a staff is convenient for estimating right angles. The contour work is the difficult work of the topographer, and the work of assistants may be very tiresome on steep side hills. The following is one method: —

Noting the elevation of a station where the topography party is, the distance out at right angles, on the higher side to the point whose elevation is the next even 5-foot point above the station, is found and scaled on the map. The next contour interval is then measured and scaled, and so on as far as necessary, when the work is repeated on the lower side of the line. The same

thing is done at the next station or the next but one, or the third, as the character of the ground may indicate; and then, looking alternately at the ground and the map, the topographer draws in the contour lines as nearly as he can judge correctly between the platted points.

The method of finding the distance to a given contour is as follows, a concrete example being given for simplicity. The elevation of station 5 is 996.3. Standing by the rod an assistant's eye reads 5.2 on the rod. The 1000-foot contour is 3.7 feet above station 5. Suppose the hill slopes up to the right. If the assistant goes out to the right until, looking through the hand level, he reads 8.9 on the rod held at the station; he will be standing on the 1000-foot contour. Therefore, one assistant holds the end of the tape and the rod at the station; the second goes out to the right till he reads 8.9 on the rod, when he notes the measurement on the tape and calls it to the topographer. The first assistant now moves out past the second, who keeps his place, he stands facing with the line rather than across it, until he finds the place by trial where the second assistant reads 0.2 on the rod which is then at a point 5 feet higher than that where the second assistant is — or on the 1005-foot contour. The distance is noted and mapped, either the second assistant passing the first till he reads 10.2 on the rod, which is the better way, or taking the place of the first, who then goes on till the second can read 0.2 again. If the slope is practically uniform for a sufficiently great distance, one or two determinations are enough, the remaining contour points being scaled in at equal distances. The method is essentially the same going down hill.

Outcroppings of rock and all timber along the line are located and drawn in; marsh lands and ordinary and high-water width of streams are shown.

The contours and other features are inked in in the office, the contours in black, streams in blue, and buildings and fence lines in red. If vermilion be used for the fences and buildings and carmine for the center line, there will be no confusion. All fence lines and land lines should be dotted, the contours very light, each fifth one a little heavier, and enough numbers placed on

the contours in convenient places that one may easily determine any elevation anywhere on the map.

It is to make such a map as results from all this work that the transit and stadia with a party of eight or ten fieldmen may be used, in the author's opinion, with great success. The party would consist of chief of party, transitman, recorder, draftsman, two or more rodmen, two or more axmen. From the author's experience the method has these two great advantages, economy and accuracy—not precision. The total distances may not be precise but there will be no errors carried along; the final differences in level may not be precise to the tenth, but they are not likely to be out more than a foot in 10 miles, and the error is compensating.

Time and again have leveling parties been checked with the stadia to find in every known instance of error that the trouble was in the leveling and not in the stadia work.*

When this method is used, the profile is made by drawing a location line on the topographic map, and calling off elevations from the map, judging of these by the contours. An excellent profile may be made in this way sufficiently correct for preliminary purposes, and probably nearer to the final location line profile than the usual preliminary line profile.

The General Procedure. — If the survey is to start from an existing line, a hub is driven at the determined initial point in the center of the track, and another some distance, 200 or 300 feet away, to give the line of the track, the angle between which and the first course of the survey is to be determined. The line of the track may be assumed as zero azimuth, or the base line, but it is better to assume the magnetic or true meridian as zero azimuth. If the magnetic meridian is to be assumed, the azimuth of the first course is not determined until the second "set up" out of the reach of the influence of the rails. If the true meridian is used, it must be determined by solar attachment, or by an observation on the sun or polaris.†

* The general method of stadia work may be found in any standard text on surveying. See Raymond's "Plane Surveying," Chapter V, Art. 237.

† Data for making these observations may be found in any surveying text-book and in the field book which will follow this volume.

If the survey starts from some point off an existing line, an initial point is established by driving a hub and witnessing it to several surrounding natural objects, so that it may again be found. In either case a guard stake is driven, about a foot to the left of the hub if off a railway, and otherwise outside the rail.

The transit being set over the initial point and oriented, that is, turned to zero azimuth with the vernier reading zero, — the chief of party indicates the direction of the first run, and the chainmen, stakeman, and axmen start. While the transit is being set, the chainmen have straightened out the chain, if a chain be used, back of the transit — with reference to the direction of procedure — and when the head chainman starts with chain, pins, and flag, the rear chainman has the chain going through his hands to see that there are no kinks. If a tape is used, it is run off the reel as the head chainman goes out, and the reel then given the line teamster for the day.

The head chainman reaching the end of 100 feet, turns, holds his flag for approximate line which is given by the transitman, and then carefully gets the distance, measuring to a pin a little to one side of the line. He then gets the line more carefully with his flag just alongside the pin, and, on its being finally correct, pushes his flag hard into the ground, and withdrawing it starts on the next measurement, while the stakeman drives the stake into the hole made by the flag. This he must be ready to do instantly the line is obtained. While driving he keeps the chain to one side by his foot so that it shall not disturb the pin nor be in his way. As soon as the stake is driven he hurries on to the head chainman to be ready to drive the next stake. He must never keep the party waiting. He will carry a number of stakes marked ahead, enough to reach the next transit point. The rear chainman must never go ahead of the rear of the chain except when breaking up and down hill, but he must always keep up with the head chainman, and should carry the rear end of the chain whenever possible, rather than let it drag on the ground.

When the end of the first straight stretch is reached, or if it is quite long, when about 1200 feet have been covered, the head

chainman selects a suitable place from which he can see the transitman clearly and the transitman can see him, and from which the seeing is good for some distance ahead — such a point is best on a little rise of ground — and signals the transitman for a point. This he does by raising his flag in both hands horizontally over his head. The transitman replies with the all right signal, sets again on his back sight and turns the recorded angle, and sets the head chainman's flag ahead. In the meantime the distance has been carefully obtained, but the rear chainman has not "come up." When the flag is set, if it is sufficiently near the measured point, a hub is driven; if not sufficiently near, a second measurement is made. When the hub is driven the measurement is made to two laterally separated points on the hub, and the line is again given. If it comes fairly in the hub, as it will if the hub has been driven straight, the head chainman calls the transitman with his hat or by some other agreed signal, and the transitman must not leave his position until so called, even if he supposes the point ahead to have been finally determined. He cannot always tell what is being done ahead, and he may much delay the party by coming on prematurely. When a straight line is being produced past a transit point, it is done by transiting the telescope and double centering. Therefore in such cases when the line has been given on the hub, the head chainman by an agreed signal, such as a whirling motion of the hand, informs the transitman that he may again set on his back-sight, which he does with the telescope inverted and again lines the flag on the hub. If both settings come on the hub, as they should with the instrument in reasonable adjustment, the tack is driven midway between the two points given and at the proper distance, and the transitman then called up. If the discrepancy of the two settings seems too great, the transitman is again signaled to reverse on the back sight and the operation is repeated until either the work is satisfactory, or until by agreement of results the error is shown to be in adjustment, when a second hub may be driven and, if necessary, a hub between for the middle point. When this occurs, the transit should be adjusted.

When the point is finally established, the head chainman draws out the chain to its full length, bringing the rear chainman up to the transit point, and the stakeman prepares stakes for the next run while the transitman is coming up.

Frequently time may be saved in open country while the transitman is coming up, by chaining ahead toward the next point indicated by the chief of party, the alignment of stakes being by eye. If the ground is very rolling so that the line is up and down hill this is difficult to do accurately, but may frequently be done with sufficient precision for preliminary work. If the alignment is not much out of the way, the measurement and angle work will not be much affected, and an error of a few inches in the position of an intermediate stake is of no consequence.

The back flagman should be watchful not to delay the transitman when he wishes a sight; he should never set his flag vertical when not holding it on the point, but should set it in the ground in an inclined position, if at all. It is better to hold it, but it need not be held constantly on the point. The back flagman should never go forward till called by the transitman, and he should never be called until the transitman has been himself called by the head chainman.

When the transit party is well started, the level party begins from the bench which has been established in the meantime. The topography party ordinarily begins the second day, but may use the first day in looking up and measuring in land lines, making notes that will be helpful on the second day.

When the transit party reaches a belt of timber or brush, a line must be cleared. Clearing line is an art not always easily acquired. An intelligent axman under proper direction will soon learn, but without the knack the ablest chopper will be slow and inefficient at line clearing. Just so much should be cleared as to permit seeing and chaining; not a stick, however small, should be cut that is not in the way. Much time is frequently lost in doing unnecessary clearing. The head chainman should keep his flag on line and well up with the clearing so that the axmen may put themselves on line by looking past the

flag to the transit. If the flag and transit are clearly visible and nothing is in the way of the chaining, nothing more needs cutting, even if a goodly tree or small sapling be within an inch of the line.

The work proceeds throughout the day with a noon intermission, and the results are mapped at night, as has been described.

Opposition will often be encountered, particularly when the line crosses fields of high corn through which a line must be cut, or through grain fields that must be trampled down. Actual damage, if it can be ascertained, should be paid for, but too frequently this has been overlooked. Such opposition as is met should be treated courteously, and the rights and duties of the respective parties fully explained. It should be made evident that the utmost possible care is being exercised to do the least possible injury; and no man on the party should be permitted to be otherwise than polite and courteous, no matter how serious the aggravation. A friend for the company may often be made from an apparently angry opponent.

The Estimate. — The items to be estimated are enumerated in the chapter on Reconnaissance. The items about which more definite information is secured by the preliminary survey are: the earthwork, its amount and classification; the bridging, culverts, road crossings, right of way, and those items depending on length of line, as track, telegraph, fencing, etc.

The estimate may be by miles, or as a whole, but it will be advisable to make it by miles summing it for the report. The profile is divided into miles by making 4 miles 53 stations long, and every fifth mile 52 stations long.

The probable kind and size of each opening is noted on the profile, the height of the bank determining the dimensions of abutments and lengths of culverts.

The length of culverts may be most easily measured by drawing a section of an embankment on cross-section paper, and with a strip of the paper measure the length at the proper depth as shown on the profile. The one drawn section will answer for all culverts. The strip should usually be inclined slightly in making

the measurement to allow for the cross slope of the ground. The cost of a culvert of given size will be

$$C = KL + M,$$

in which K is the cost per foot of length, and M the cost of the head walls.* The best method of estimating is to make a diagram on cross-section paper. The cost of each size of culvert will be represented by a separate straight line, the ordinate to which at an abscissa L will be the total cost of the culvert.

Walls for openings may be estimated from tables or a diagram. To make a diagram the quantity in two walls between coping and bottom of footing, including the wings, is computed for walls of heights varying by 5 feet and plotted on cross-section paper with axes of height and cubic yards. The points are connected by a curve, ordinates to which at any height abscissa will be the cubic yards for that height. The coping is constant, and, if of the same class of masonry, may be added, otherwise it must be kept separate. Or for quite approximate results the following equation may be diagrammed for cubic yards, including the footing, the abscissa being the height between coping and footing, taken to be 4 feet less than the height from grade line to bottom of footing course.

$$Q = 0.03\,H^3 + 0.5\,H^2 + 3.2\,H;$$

Q is cubic yards for two abutments.†

This formula does not include foundation masonry below the footings. Such masonry must be added.

* If the quantity of masonry is wanted, the cubic yards, K, in two head walls are computed, and the cubic yards, f, per foot of barrel. Then if w be the width of road-bed, S the side slope, and h the center height of embankment where the culvert is to be built, the total quantity of masonry in the culvert is given approximately by

$$C = f(w + 2\,hs) + K = 2\,fhs + (fw + K)$$

which may be diagrammed as a straight line on axes C and h.

† Full diagrams and tables for estimates will be found in the field book to follow this volume.

A very low opening built without coping or footing cannot be estimated by this formula.

The formula will answer for bridge abutments in which the masonry is not more than 3 feet thick under the coping.

Large bridges must be estimated separately. They will not ordinarily be many. If cylinder piers are to be used, the cylinders must be estimated as steel by the pound, and the filling as concrete by the yard, and any piles driven to hold them, as piling driven. The routine work that may be left to the assistants is the estimation of earthwork.

For this purpose the work will be divided into four classes: 1. All that earthwork that will be wholly cut or wholly fill, and that may be called level across the surface. 2. All that earthwork that is wholly cut or wholly fill, that must be considered to have a cross slope. 3. All that earthwork that will be side hill, that is, each cross-section partly in cut and partly in fill. 4. All rock excavation.

It is presumed that either the levelman has recorded the cross slopes or they are shown on the contour map. What sections may be considered level across may be determined by remembering that a cross slope of 1 in 10 will be erroneously calculated by the level section method by about 2 per cent, the truth being in excess, and a cross slope of 1 in 5 will be erroneously calculated by about 8 per cent.

What stations will give side hill sections may be determined when such work is expected, by platting a road bed and slope on cross-section paper, one side cut and the other fill, and placing a straight edge of paper, or better a transparent ruler, across the drawing at the cross slope angle for the given station and through a point above or below the center of the road-bed a distance equal to the depth of cut or fill shown on the profile. This determination will be made when the computations are made.

Sections known to be in rock, if not irregular, may be computed as earthwork, using, however, the rock slopes and road-bed.

Each complete cut or fill is computed separately and its total penciled in on the profile. The work may be done by tables or

diagrams. The author advises the use of diagrams as far quicker and amply precise for preliminary work.

By either method the depth of cut or fill is called from the profile and the corresponding cubic yardage for a station taken from the table or diagram. If a diagram be used, the successive station quantities may be laid off one after another on a strip of paper, the total length being finally applied to the diagram scale and the whole yardage of the cut or fill obtained without adding. A fractional station may be estimated at the same fraction of a station quantity that the fractional distance is of 100 feet.

If the general cross slope for a given cut or fill is about the same for all stations, the quantity may be computed by the level section method, and the whole increased by a small percentage, depending on the slope and depth of cut or fill. The following percentages may be used for approximations for a 5-foot cut; they are about 50 per cent too large for a 10-foot cut, and should be increased about 50 per cent for a 2.5-foot cut.

Slope	Per cent Increase
$2° 52' = 1$ in $20 = 5$ in 100	0.5
$5° 45' = 1$ in $10 = 5$ in 50	1.8
$11° 32' = 1$ in $5 = 5$ in 25	7.2
$14° 29' = 1$ in $4 = 5$ in 20	12.0
$19° 28' = 1$ in $3 = 5$ in 15	22.5
$30° 00' = 1$ in $2 = 5$ in 10	60.0

These values are roughly approximate, and the more accurate method is to use a diagram for sloping ground.* This diagram may be made by plotting the following equation on cross-section paper:—

$$Q = \frac{100}{27}\left(\frac{C^2 r^2 s}{r^2 - s^2} - \frac{w^2}{4s}\right)$$

in which w is the width of road-bed at subgrade; C is the center

* Wellington's or Trautwine's diagrams may be used.

height plus the height of the grade triangle, $C = c + \frac{w}{2s}$; r is the cross slope of the ground $\left(\frac{hor.}{vert.}\right)$, and s is the side slope of the cutting. The second term being constant per station may be omitted in the platting, when a single diagram will do for any road-bed width and one side slope. A separate line will be drawn for each of several values of r, enough to cover the work. The best way to designate the different lines for the several values of r is to number them with the horizontal feet for a rise or fall of 5 or 10 feet, the contour interval. If the slope is by angle, they may be numbered with the degrees for which they are drawn.

Side hill sections may be estimated by applying the straight edge as already indicated to an ideal section, calling off the base and side height indicated for cut and for fill separately, and finding the corresponding volumes from a table of triangular prisms* or a corresponding diagram. The value of a triangular prism of area $\frac{a \times b}{2}$, a and b being base and altitude respectively, is $\frac{100}{27} \frac{a \times b}{2}$, and this may be diagrammed as a series of straight lines with axes a and cubic yards, one line for each of a sufficient number of values for b.

In estimating cutting, the necessary allowance for ditches must not be overlooked. This is a constant per station, and is the yardage for three ditches, the two roadway ditches and one surface ditch.

Right of Way. — The cost of right of way depends on the value of the land taken and the damage done by the taking. If the farmer's field is badly cut by the railroad line, the damage may be considerably in excess of the market value of the acreage taken. In making preliminary estimates it will be not unwise to figure on at least twice the market value for farm land, and in towns

* Allen's Tables, or those of the field book following this volume, may be used.

or cities it will be well to secure a local real estate agent's opinion of values and damages.

The width of right of way depends on the magnitude of the work, and the way it is done. Omitting consideration of station grounds, which are quite variable and depend on the probable or actual business of the station, right of way on the open road must be of sufficient width to permit all building operations to be carried on within its limits, except in wild, unoccupied country or where of necessity temporary privileges are secured outside the right of way. Such privileges must be included in estimates if they can be foreseen. If an embankment is to be made from borrow pits alongside, the width of right of way required must equal the width of embankment base plus the width of the berme bank, plus the width of the borrow pits, with a small surplus for fencing.

A fill 14 feet wide on top, 10 feet high, with side slopes of $1\frac{1}{2}$ to 1, and 6 feet of berme on each side, requires 56 feet between inside edges of borrow pits. With an allowance of 2 feet on each side for fencing, there are but 20 feet of width left on each side of a 100-foot right of way for borrow pits, and if the sides of these pits be given a slope of $1\frac{1}{2}$ to 1, as they should be, they cannot be made deep enough to supply the material for the adjacent embankment. If the berme be 5 feet instead of 6, and but 1 foot be left on each side for fence posts, the pits must be nearly 7 feet deep to supply sufficient material. More than 100 feet of width is then necessary. If the fills are made from adjacent cuts, a less width is sufficient. Fills should not be made from adjacent borrow pits except where absolutely necessary.

An excavation of 20 feet base width, side slopes of $1\frac{1}{2}$ to 1, a height of 20 feet, and a berme distance of 6 feet to a surface ditch 5 feet wide on the upper side of the cut, requires more than 50 feet for the half width of right of way. In ordinary rolling country where the fills are made from the cuts, 100 feet is generally wide enough for right of way, and in towns and cities where there is little grading for a surface line, the width should be ample to provide for subsequent elevation of the tracks when the certain

abolition of grade crossings comes. The usual width taken is 100 feet. The profile must be studied for variations of this width, and an ample width purchased at the first buying for double track construction; it will often cost more to get a few extra feet width than the whole original cost of the adjacent first width.

CHAPTER XX

THE LOCATION SURVEY

General Statement. — The location field work is essentially like that of the preliminary survey, except that the straight lines are now joined by curves, the topography party is omitted, the leveling party may take cross slopes with a clinometer, and soundings may be made for rock in what are to be earth and rock cuttings and at stream crossings for foundations. The line is not now picked ahead by the chief of party unless the planned line seems to be running otherwise than planned. A plan has been devised based on the preliminary survey, notes have been made up from this plan, and a line corresponding to these notes is laid out on the ground. In simple cases, short branch lines, the location may be made by trial without a preliminary line, or with occasional short lines run ahead of the location for information as to grade to be used, curve to fit a particularly bad hill, or other matters. The important parts of location are the planning of the line and the fixing of the grade on the profile. Methods that have been proved satisfactory for this work will be given, and a few details of the methods of running in curves.

Frequently the location follows close on the preliminary, and is often made by the same party. If an independent preliminary of the whole line is not required, the company being satisfied to order the location from the reconnaissance report, then the best method is to run the preliminary ahead for, say, 10 miles, 5 miles on either side of the camp, plan the location of the first portion while the last is being run, and then locate the 10 miles before moving camp.

Devices for Securing Low Grade. — There are two principal devices for overcoming high mountain summits — spirals or loops

and switch backs. Other devices are inclined planes operated by cables, and rack railroads.

A spiral loop is formed when in developing a line to secure low or possible grades the line is made to cross itself at different elevations. The most noted of these spirals in America are the Tehachipi loop of the Southern Pacific crossing the Sierra Nevada Mountains in California and the Georgetown loop of the Colorado Southern in Colorado. The former is what is known as a tunnel spiral, the line of lower level at the crossing being in tunnel, and the latter is a bridge spiral, the line of upper elevation crossing that of lower elevation on a bridge. The tunnel spiral occurs when the development is around a hill peak spurring out from the main ridge, and the bridge spiral when the development is on the hill sides of a stream basin. The most famous spirals in Europe occur on the Mt. St. Gothard Railway, but here they cannot be called naturally located spirals, since they are simply rising curves, almost circles, practically wholly in tunnel in the side of the mountain. There is a series of them on each side of the mountain.

The switch back occurs only in extreme cases when there is not supporting ground for a doubling back curve or opportunity for a spiral. The line doubles back on itself by means of a stub end and a switch.

These switch backs are put in as a last resort, and should always occur in pairs, the two spurs of each pair being reasonably close together that the backward movement of the train may be a minimum. The profile of the stub end should be a curve upward toward the end in order that the grade may help to stop and start the train.*

Planning the Location. — With the preliminary profile before him to show where it is desirable to be higher or lower, the chief of party picks out points on the preliminary map, through which,

* Full maps and profiles of various forms of developments that have been used will be found in Wellington's "Economic Theory of Railway Location," Beahan's "Field Practice of Railway Location," and Lavis' "Railroad Location Surveys and Estimates."

or as near as possible to which, the located line should lie. He may sketch a light pencil line through these points and then with thread for straight lines and templates of curves of various degrees, drawn to scale on tracing cloth, he determines an approximate location line, and pencils it in on the map. The curves should be drawn at an offset, if the scale be large enough to show it, for such easement curves as are to be used. If the engineer is satisfied with his first location line, he will have notes made up for it. If not, he may have the profile of it called off from the contour map and penciled on the preliminary profile to note the effect of the shift in line. A new grade line may be drawn in, and if necessary further fitting of the line on the map may be made. When the location appears to be satisfactory, the notes will be made up and the line may be run in on the ground.

When in planning the location a stretch of maximum grade is reached, the line of this is determined by platting the grade contour. To do this a point is found on the contour map that is opposite (at right angles to the line) the last determined station of the located line where the maximum grade is to begin, and that is of the same elevation as the grade line at that point. The horizontal distance required for the maximum grade to rise or fall through a height equal to the difference between the point assumed and the next higher or lower 5-foot contour is then taken in the compasses, and with the needle point on the assumed point on the map, a small arc is drawn cutting the next higher or lower contour. Then with the horizontal distance required for 5 feet change of level on the maximum grade, a series of arcs is described, the intersection of each with its contour forming the center for the next. This proceeds until the top or bottom of the hill is reached, when a light pencil line may be dotted in, connecting the several intersections. Except where abrupt ravines are crossed into which the line cannot go, this dotted line will be a line lying on the surface of the ground and rising or falling at the required maximum grade. It is most common to work these grade contours down from a summit each way if the ruling grade occurs on both sides.

The preliminary line will indicate about how much curvature there is likely to be on the hill, and the grade should be modified for the curve compensation before using it as described. The total loss for compensation on the hill divided by the estimated length of the grade will be subtracted from the maximum rate to give the real rate. The estimated length of the grade will be the height to overcome divided by the rate of the grade, therefore a depth of summit cut is assumed, the elevation of grade at the bottom known or assumed, and the difference is the height to be overcome. If this be H, and if R be the rate of the maximum grade, and C the total estimated curve compensation in vertical feet, then

$$L\left(R - \frac{C}{L}\right) = H$$

$$L = \frac{H + C}{R}.$$

The curve compensation is found by multiplying the probable total number of degrees by the adopted compensation per degree, 0.025 to 0.04 feet.

The location line is planned to follow the grade contour as nearly as practicable, having consideration for curvature, distance, and class of material to be excavated at the various points. In general the location should be straighter than the grade contour and should cross it back and forth, making alternate cutting and filling.

Before a final line is decided on, it is best for the beginner to draw two or three lines of varying curvature, distance, grades, and rise and fall, and compare them as to ultimate economy by using the capitalized values for one unit of curvature, distance, and rise and fall, adopted for the road, offsetting the differences thus found by the differences in cost due to variations in earthwork, and finally adopting that line that appears to have a balance in its favor. After adopting one line, the matter may rest for a day or two, and then be studied again, often with much gain, an almost entirely new arrangement suggesting itself. The ruling grade does not enter the problem, as that was determined by the

route selected by the reconnaissance. When the line finally adopted is located it will be studied for improvements.*

Computation of Notes. — The tangents of the final location line are produced on the map to their intersections, and the coordinates of these points measured with great care. The azimuths and lengths from intersection to intersection are then computed. The deflection angles are determined from the computed azimuths and these angles with the radii of the chosen curves and such easement curves as are used, give the data for the tangent distances, which properly subtracted from the respective total tangent lengths give the lengths of tangent between curves. If the beginning is a curve from an existing track, the tangent distance of that curve plus that of the next curve subtracted from the distance between intersections, gives the length of the first tangent. The central angles divided by the degrees of curves give the lengths of curves.

The stationing is determined by calling the beginning of the line zero, adding the length of the first curve, if the line starts with a curve, for the station of the first P.T., to which the succeeding tangent is added for the station of the next P.C., etc.

If the curves are offsetted for spirals, the P.C. and P.T. are opposite the offsetted points. It is suggested that the beginning of the first spiral be called P.S., point of spiral; the junction of spiral and curve, P.S.C., point of spiral-curve; the junction of curve-spiral, P.C.S., point of curve-spiral; and the end of the final spiral, P.S.T., point of spiral-tangent. No regular notation for these points has been adopted.†

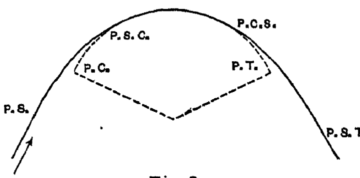


Fig. 89

* See paper by Professor Taylor in the Appendix. A determined 1 per cent grade line was reduced to a 0.65 per cent line.

† The spiral elements used in computing the tangent distances may be had from any good book on spirals. The field book following this volume contains the methods approved by the American Railway Engineering and Maintenance of Way Association.

The computations should be made systematically in a note-book and not on scraps of paper or pads; should discrepancies be discovered, the work is wanted for reference. The notes resulting from the computations are arranged in a field book. A good form is shown in Fig. 90. The checks measured with great care on the preliminary map should also be entered in the note-book for field use. Each intersection of location and preliminary line should be scaled for station of intersection on both lines, and except where the angle of intersection is small, these should agree with subsequent field intersections. Where the intersection angle is very small, such slight variations as may exist between map scaling and field measuring might cause seemingly large discrepancies in stations of intersections.

Curves are not usually run by azimuths, but by deflection angles, the tangent azimuths being computed and noted for a check on the angle work. The form of note-book is the same whether azimuths or bearings be used.

Running in Curves. — The head chainman is informed of the station of the first — or next — P.C., and the offset for the spiral. When he has reached this point he sets a hub and another some distance farther on, or back, as the character of the ground may indicate. When both have been set, he calls the transitman up. While he is coming up the chaining party set hubs at the spiral offset opposite each of those set on the tangent, using such means for securing a right angle as the length of the offset may require. For a very short offset the direction may be guessed at; for an offset of more than a foot the chain may be used to make a right triangle, the sides of which are in the proportion 3, 4, 5, or a light wooden square may be carried.

The transitman sets up over the offsetted P.C., using the other offsetted point for a fore or back sight, as the case may be, and turns to the successive azimuths of the several chords as the chainmen measure around the curve. When the P.T. is reached and set, the head chainman having been informed of its station, the transitman comes up, uses the P.C. for a back sight, turns to the direction of the tangent, has a point set opposite the P.T.

Station	Line	Defl. Notes	Tangent Azim.	Date, Weather,	Begin Sta.	
	4050 ft.					
+ 75 P.T.	Tangent	8° 30	15 163° 20′			
40		7° 00′				
39	425 ft.	5° 00′				
38		3° 00′			P.S.C. 38+55	1° 24′
37	17° 00′	1° 00′			37+20 +85	0° 58⅓′ 0° 37⅓′
136+50 P.C.	4° Curve R	0° 00′		Spiral 210 ft. 6 Chords 35 ft.	+50 36+15	0° 21 0° 09⅓′
136			15 146° 20′	A = 4° 12′ O = 128 ft.	+80 P.S. 135+45 Defl.	0° 02⅓′ 0° 00′

Fig. 90

on the tangent, and sets another point some distance ahead from which a second point is set on the tangent. The transitman moves his instrument to the transit hub set opposite the P.T. while the second hub is being set, uses it for a fore sight, and the work proceeds.

If the spiral curves are located by deflection angles, the difference in procedure will be obvious.

The spirals will be located later, when the construction is determined, and the work is staked out. If the offset is several feet or enough to make a difference in the profile, the level party should use the point midway between the two P.C. and P.T. hubs for levels.

When spirals are not allowed for on the original location, the method is the same, omitting the offsetting for the spirals and the extra hubs on tangents. Spirals should be used on all new location.

Fixing the Grade Line. — When the profile is drawn, a grade line will be drawn on it, and it is well here to spend much time in careful study, for several hundred dollars a mile may readily be saved by a few hours' study of almost any first location profile, and not infrequently the saving may be measured by thousands instead of hundreds. The study must be from two standpoints: —

1. The work of the locomotive. 2. The cost of earthwork.

The first grade line is determined by stretching a fine black thread in a broken line along the profile so as to equalize the cut and fill as nearly as may be judged by eye, taking care to keep within the limiting grade and not to introduce very deep sags, not more than 20 feet as a rule, if it be practicable to keep within this limit. In judging of the equality of cut and fill one must have in mind something of the relative volumes for equal depths of the two classes of work. This may be judged for the road-beds used by reference to Table 11, page 255. It will be observed that for 14-foot embankment road-bed and 20-foot excavation road-bed, with equal slopes of $1\frac{1}{2}$ to 1, the volume of cut, including ditching, is about $2\frac{1}{3}$ times that of fills when the height is about 1 foot, about $1\frac{1}{3}$ times embankment for a height of 5 feet, about 26 per cent in excess for 10 feet height.

The locomotive that it is expected will be used on the road — or, if that is not known, one that in the judgment of the engineers should be used — loaded for the ruling grade, is supposed to start from the beginning of the line and make the best speed possible, within its maximum limit, over the division on the grades drawn. A velocity profile that may be realized is drawn, and the character of the rise and fall studied. If any of Class C or B appears, the value of eliminating it will be considered and offset against such additional cost as the best rearrangement of the grades to accomplish it necessitates. If additional rise and fall of the comparatively harmless class can be introduced, particularly as sags, to reduce the grading, it should be done if the gain in earthwork more than offsets the loss by increased rise and fall. It is not true that any change may be made in the grade line so long as it is kept well under the velocity profile and not more than, say, 28 feet under it, without interfering with successful operation, but it is approximately true; and it is true that very short grades steeper than the ruling grade may be introduced to save money, if their summits are well within the velocity profile and it is reasonably certain that the speed of approach shown by that profile may be attained. In constructing the velocity profile it is particularly necessary to have in mind the alignment, as high speed would not be permitted at sharp curves in a sag nor on long bridges, and the resistance of long uncompensated curves must be considered, this resistance being always added with the plus sign to the grade resistance, which may be plus or minus.

Vertical curves changing by 0.05 per station in sags and 0.10 per station on summits should be used to join all grade lines. Where on very heavy work these small rates of change greatly increase the earthwork they may be doubled. It is well to draw templates of the vertical curves on thin tracing profile paper to use in fitting grades on the location profile.

When the best arrangement of grades that seems possible has been made, the places where further improvement seems desirable are studied in detail with the map for possible changes of alignment that will permit changes of grade favorable both from the

operating and first cost standpoints, not omitting consideration of the cost of changes in distance. Such changes as seem advisable are drawn on the map, probable profiles penciled on the profile, and such grade changes as seem wise are made. If the party is still in the vicinity, the new lines are run branching from and uniting with the old, keeping the same total stationing, introducing and recording a long or short station for this purpose at the close of each change. If the party has left the vicinity, the notes of desirable changes are entered in the note-book and on the map, to be made at a convenient later time, either by a party following, by the same party going a second time over the whole line, or by the resident engineer when he shall have been located for construction. If possible the change should be made while the original party is still in the field.

When a satisfactory grade for operation is secured, the study for economy of first cost is made. For this purpose an approximate mass diagram is constructed and the desirability of changing the grade lines by moving them parallel to themselves, or even changing their rates to equalize and minimize the earthwork and haul will appear. Any changes may now be made that do not increase the ruling grade or the rise and fall of Classes B and C, and even such changes may be made if they can be shown to be economical when the saving in earthwork is offset against the cost of the rise and fall added.

It is unusual to put so much study on a location, but there is a tendency in this direction and every careful locating engineer should encourage it. The grading of an average single track road in the Mississippi Valley costs perhaps $10,000 a mile, its location including all surveys, perhaps $100 a mile. The location cost could be doubled to save 1 per cent of the grading cost, and it is true that a very much less expenditure than this will in almost every instance save five times 1 per cent of the grading cost, to say nothing of the far larger possible saving in operating expense.

Some Principles of Location. — 1. Traffic varies as the square of the population, and at equal cost that line is best that shows the greatest population *per mile of road.*

2. The rate is from the "door of the consignor to the door of the consignee," therefore the line should go as close to the business at stations as possible.

3. The line and grade should fit the country. A 0.4 per cent grade should not be attempted in a 1 per cent country, but it should be demonstrated beyond question that the country is 1 per cent country; sufficient traffic will convert a 1 per cent country into a 0.4 per cent country. A 2-degree curve should not be used on a 10-degree hill, but it must be demonstrated that the hill is a 10-degree hill; sufficient traffic will convert a 10-degree hill into a 2-degree hill or a straight line and tunnel.

4. When money is available, the location should be on a strictly economic basis, leaving no improvement in line or grade unmade that can be shown to be profitable, but —

When money is limited, the location should be the best that the available money warrants.

The principles of Part II of this book should be used in determining the most economical location.

Report. — The report on the location will be essentially a report of character of alignment and cost, with a statement of such alternate details as may seem worthy of consideration. A condensed map and profile is convenient for use with such a report and one such map and profile for a proposed short connecting line is shown on Plate XIV. *

* Kindly furnished by Mr. W. D. Taylor, Chief Engineer of the Chicago and Alton Railway.

CHAPTER XXI

CONSTRUCTION SURVEYS

Organization: Short Line. — For a small extension, or line, of 10 miles or less, the engineering force necessary will be an engineer in charge, an instrument man, a rodman, and an axman. If there are any important structures, as pile bridges, masonry abutments or piers, or buildings, an inspector should be employed at each structure in progress at one time. If the plans for all bridges and buildings must be made, as is the case when the line is not a part of a larger system having standard plans and an engineering office, a draftsman will be required. If the construction is in progress along the entire length at the same time, it may be necessary to have a team for the instrument party, and a horse or horse and light road wagon for the engineer in charge.

The engineer in charge performs the duties assigned in more extensive work to the chief engineer, and in addition does the inspection work and designing of the resident engineer mentioned hereafter; that is, he should go over the work daily and give it a general inspection, direct the regular inspectors and give such orders and directions as may be necessary, and determine the dimensions and forms of all structures.

The instrument party, consisting of the instrument man, rodman, and axman, makes all the field surveys and measurements, and computes all quantities except those furnished by the special structure inspectors.

The draftsman, under the direction of the chief engineer, makes all drawings of plans for structures, and assists in such office work as there is to do, such as correspondence, the making of estimates, and filing. If from the first inception of the enterprise to its finish everything is done in the least possible time, so that preliminary survey, location, and construction may all be in progress

at one time, at least two additional men to act as chainman and flagman will be required. If the time of preparation is extended so that the location, staking out, and making of all plans may be completed before the construction begins, the force during construction may consist of the engineer in charge, and two or three helpers. Economy usually means the larger force for the shorter time.

If the line is less than 5 miles, it will perhaps be possible to dispense with the draftsman and the teams.

Organization: Long Line. — When the work is more extensive, say, 20 miles or over, and is to be prosecuted at several places at one time, an organization varying but little from that already named will be required on each section of 8 to 10 miles.

When the work covers, say, 100 miles or more, the following organization will be required: —

A chief engineer, an assistant chief engineer or associate engineer, a division engineer for each 30 to 50 miles, a resident engineer for each 5 to 10 miles. In the chief engineer's office there will be a clerk who is a stenographer, and one or more draftsmen who may also do clerical work at times. The associate engineer will be in the same office. In each division engineer's office will be a draftsman who may also do clerical work, and at times additional help may be required.

Each resident engineer will require in his party a rodman who can use field instruments and draw, an axman, and during the period of staking out work one or two tapemen.

In addition to this force principal assistant engineers are sometimes employed, ranking about with division engineers. These are in charge of special departments of work, as bridging, or in charge of particular important structures, as an unusually large bridge or viaduct, a long or difficult tunnel, etc. Inspectors should usually be employed, one on each piece of important masonry work, or building. There should also be an inspector of track laying, and one or more tie inspectors. A special party under the direction of an intelligent land surveyor may be advantageously used to make all right of way maps and records. The

surveyor will be connected with the office of the associate engineer, to whom he will report.

In general it may be said that with the possible exception of the clerks and axmen, all of the engineering force should be men of greater or less experience who are making, or expect to make, engineering their profession. However, while the best masonry inspector is a trained engineer who has had experience in masonry construction, the next best inspector is an honest, intelligent mason; and the best tie inspector is a fearless, but sensible lumberman or farmer who knows timber. If the ties are furnished from timber along the line of the road, an inspector will be required for each one or two divisions. If the ties are all brought to the road by rail or vessel, the inspector should be located at the point of shipment.

It may be necessary to employ also a material clerk and one or more assistants and laborers, if considerable quantities of ties, timber, rails, and bridge material must be accumulated at some one or more depots along the line. The material clerk will keep record of all material received and forwarded and will forward material to the front as it is required.

The assistant chief engineer has immediate personal supervision under the chief engineer of all the engineering force and work, and all communications from division engineers to the chief engineer, and from the chief engineer to division engineers must go through the assistant chief engineer. All reports or requests for instructions or communications of any character concerning the work in hand should go from the officer in whom they originate to his immediate superior or subordinate, as the case may be. Departure from this rule is almost certain to bring confusion to the work and personal unpleasantnesses to the force. Emergencies may arise necessitating a departure from this rule, but when they do, both parties to the infringement should immediately notify the intermediate officer concerned.

All general plans for the road-bed, track, and structures will be made under the supervision of the chief engineer, who will, with the assistance of the attorney of the road, and under the chief

executive officer, president, or general manager, draw all specifications, and make all contracts for materials or labor. His office, through the assistant chief engineer, will furnish division engineers with copies of all general plans for ordinary structures, forms of excavations and embankments, specifications for all classes of work on their divisions, and special plans for unusual work or structures when they occur.

All alignment and grades must be approved by the chief engineer before they are adopted for construction. The chief engineer should go over the entire line as often as possible, not less frequently than once in three months, unless the work is of such magnitude as to make this impossible.

The chief engineer is the general designing and executive officer of construction, and the assistant chief engineer is his field executive.

The division engineer, from surveys and information furnished by the resident engineers, and following the general plans furnished by the chief engineer, makes all detail plans for the various small structures on his division, and writes bills of material for these, designating each by its station on the map or profile. Copies of these plans and material bills are furnished the chief engineer's office. The division engineer may also make special designs for special structures, but these when so made must be approved by the chief engineer. The division engineer makes monthly returns to the chief engineer of all work done and materials supplied on his division. He should go over his division at least once each month, and oftener, if possible. He will furnish each resident engineer under him with map and profile of his residency, with plans for all structures, and bills of materials, and with copies of the specifications for work to be done on the residency.

The resident engineer, with his party, makes all surveys and measurements required in staking out earthwork and structures for construction, and is in immediate charge of the work on his residency. He acts as inspector except as special inspectors are employed, and these should be subject to his direction. The

resident engineer makes monthly returns to the division engineer of all work done and materials furnished on his residency.

The Work of the Residency. — The resident engineer being furnished with notes of alignment, records of bench marks set on location, and a profile of his residency, first retraces the line with great care and reëstablishes all transit points, particularly points of curve and tangency; if errors are found he makes note of them, sometimes introducing long or short stations to make the notes agree with the line as actually laid out. All transit points should be carefully referenced with stakes set where they will not be disturbed by construction work. They may be established by intersecting transit lines, and if they come where deep cuts are to be made, care must be taken to so locate the reference points defining the lines that when the cut is made it will still be possible to see the point to be replaced from the reference points.

He then runs check levels over the line, checking both the profile and the bench marks, and setting additional bench marks about 1000 feet apart. These should be set where they will not be disturbed by the work of construction, and about on a level with the grade line near them, rather than in hollows or on tops of hills. This is to facilitate leveling as the work approaches completion.

If discrepancies are found in the location notes, the resident must check his own work to be sure the error is not his. Copies of the corrected line and level notes should be furnished at once to the division engineer, who will in turn furnish them to the chief engineer.

The next step is to mark the boundaries of the right of way for clearing, making notes of the amount of clearing and grubbing in accordance with the provisions of the specifications.

While the clearing is going on, those portions of the line that are clear may be cross-sectioned for construction. During this period unless a special party is assigned to this work, surveys for drainage areas for the several openings and for maps and descriptions of right of way areas may also be made, and permanent corners may be placed at the intersections of railroad and other land lines. Sounding and test pits may be

made at the sites of important structures, and special surveys at important bridge or viaduct sites. These surveys should be such as to furnish accurate contour maps of the sites, information as to high and low water, character of bottom, and depth to rock or other good foundation material at all points where it may possibly be wanted for purposes of design. Notes of all surveys should be full and explicit, with sufficient explanatory matter to enable a successor to fully inform himself as to what has been done and to take up the work where the original resident may for any cause have to leave it. The notes should all be in books and not on scraps of paper, and should be fully illustrated with well-drawn sketches. There is no other form of notes so entirely satisfactory as well-made sketches. Many other special surveys, such as those for station sites and sidings, water supply stations, road and stream changes, etc., may be required from time to time, and as the work advances the various structures must be staked out.

The resident engineer should familiarize himself with the possibilities of the country adjacent to his residency, particularly as to the location and character of building stone and timber suitable for structures or ties. He may also investigate water supply possibilities as time permits, remembering that pure, soft water, as free as possible from scale-producing minerals, is the first desideratum, and that a gravity supply at a reasonable cost is usually cheaper than a pumped supply.

The resident engineer should be firm, but courteous and reasonable, in all his dealings with the people living along or near his residency. The people will often be unreasonable, but the resident must remember that the man who loses his temper loses his case.

The resident engineer should go daily over all work under way and give such directions as may be necessary. His rodman and party should be competent to do such instrumental work as may be required at times when the resident must be elsewhere.

The resident should see that the work is being done correctly as to method, and that it is being kept to time. He should furnish new line stakes, and grade stakes, as often as the contractor

doing the work requires. When the embankments and excavations have been finally brought nearly to grade, the resident will drive stakes at the center and edge at each station so that their tops shall be exactly at grade. The tops are then chalked. On curves the center stake will be put at profile grade with the outer stake higher and the inner stake lower by equal amounts sufficient to give the required cant to the track. The contractor must be required to finish his work to these stakes, the resident noting that the bank slopes are not hollow nor the cut slopes bulging, and that the road-bed is not sagged or raised between stations.

As soon as possible after cross-sectioning, the resident engineer and his party will compute the volumes to be moved, and at the close of each month will estimate the portion of work done, and furnish such estimate on proper blanks to the division engineer. For earthwork, the estimates are made by center levels over all work in progress, noting that these do not misrepresent the amount of work done. For masonry, that actually done is measured. Sometimes an allowance for materials delivered, but not yet used, is made. This is not the best practice, and should be done only on the order of the division engineer, unless the specifications expressly provide for it. Specifications usually call for timber in place in the structures, and it should be estimated only when so placed. The same thing applies to iron in structures.

A progress profile should be kept up, and a copy on vellum or thin profile paper furnished each month to the division engineer. Such profiles are made on the original profile by drawing the profile of the work as it appears at the time of making the monthly estimate, and tinting the space between the last and new profile with water color. A general scheme of colors — one for each month — should prevail on the entire line.

The resident engineer may be required to keep a record of the force employed by the contractor; whether he is so required or not, he should do so for his own benefit. A careful account from the foremen's time books checked by the engineer's observation should be taken each day; whether or not the engineering

department requires it, such an account will be valuable to the resident in connection with the monthly estimates, and as determining the actual cost of the work, which may be an item of knowledge of great value to him at another time.

He should keep a diary of all that he, his party and the contractor, do from day to day. He should carefully study the methods used in doing the work, trying, if possible, to determine the reason for adopting the particular method chosen. He will not offend if he is able to suggest better methods, making sure first that they are better.

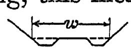
When the grading, masonry, and timber work are completed, the resident engineer will set track centers for the track laying. These should be very stout hubs about 18 inches long, firmly driven at each station, a tack marking the exact center line. On curves of 4 degrees or over the hubs should be set every 50 feet, and on very sharp curves every 25 feet. The hubs should stand from 4 to 6 inches above the surface. In a timbered country the axman of the resident's party will accumulate a supply of these hubs at odd times during the progress of the grading.

If part of the ballast is placed before the track is laid, ballast grade stakes, with tops flush with the proposed ballast surface, must be set after the subgrade surface is completed.

If the ballasting is done after the track is laid, the common practice, a profile of the top of the rail may be made to a large vertical scale, and stakes set for the top of the rail proposed after the required amount of ballast has been placed. Levels taken on the rail after the work is done will check the amount of ballast under the ties.

With the completion of the track the work of the resident engineer usually closes, and he is dismissed or moved elsewhere to do other work. If he has shown sufficient ability and interest in his work and the welfare of his employers, he will probably be retained. Ability is of two kinds: ability to do a set task, and ability to see what needs to be done and to do it. The second is the more valuable quality and should be cultivated, but it cannot be acquired by a man who has none of it as a birthright.

Staking out Earthwork. — The cross-section of a railroad embankment or excavation being approximately as shown in Figs. 91 and 92, "staking out" the work consists in finding the height C from ground level to grade level at each station, the heights h_r and h_l from ground level to grade level at the points where the side slopes intersect the ground and the distances d_r and d_l from the center to these last named points, and placing stakes properly marked at A, B, and E. These quantities are all used directly or indirectly in computing the area of the cross-section. The sections shown are called three level sections because elevations are found at three points. If the ground is level across, the *h's* and C are the same, and the section is known as a level section; if a cross profile of the ground is quite irregular, the section is known as an irregular section, heights from ground to grade level, and corresponding distances from the center being taken and recorded at all marked changes of slope. Level and irregular sections are shown in Figs. 93 and 94.

Both figures show embankment cross-sections; excavation sections would be the same inverted, hence one form will suffice for illustration. If the line lies on a side hill in such way that the ground surface intersects the grade level within the limits of the road-bed width, the section is a side hill section of which three forms are shown in Figs. 95, 96, and 97. In all of the figures, 91 to 97, w is the width of the finished road-bed at subgrade, that is, below the ballast. In a cutting, this means at the level of the top of the side ditches, thus  or  thus according to the form of road-bed.

In all cases shown in the figures, stakes are set only at A, B, and E, except that in side hill sections a grade hub and guard stake are driven at G (in Fig. 96 at A).

In Fig. 94 no stakes are set for the heights a, b, e, f, and g, because these would be removed or covered in the grading, and the measurements are made only for the purpose of getting the area of the cross-section, while the stakes at B and E are put in to mark the limits of the work. The stake at A is removed before work begins and placed alongside B or E. The stake at A, which

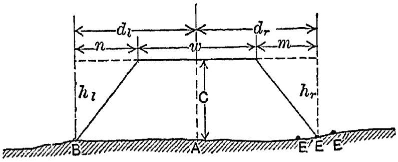


Fig. 91

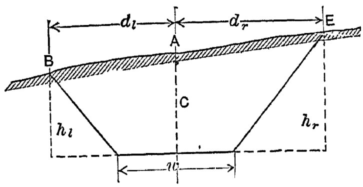


Fig. 92

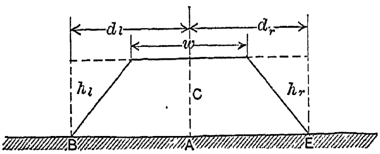


Fig. 93

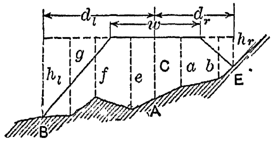


Fig. 94

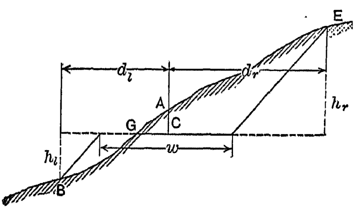


Fig. 95

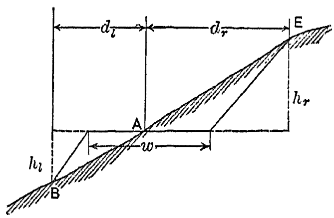


Fig. 96

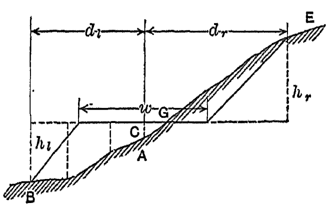
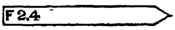
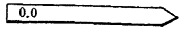


Fig. 97

is the center line stake, and hence is marked on its near face with the number of the station, is marked on its forward face with the depth of the cut or fill c, and a letter F or C, meaning respectively fill and cut, thus 

meaning "Fill 2.4 feet." The side stakes, called slope stakes, are marked with the height h_r or h_l, as the case may be, on the side facing the center, and on the side from the center with the number of the station and the letter R or L, signifying right or left side of the center. To the figures for h_r or h_l the letter F or C is prefixed, as on the center stake. At the point G in the side hill section a stake is driven till its top is just at grade level; the top chalked with kiel or marking crayon, and a guard stake driven alongside marked 

on the side facing the grade plug. Instead of "0.0" the word "grade" may be lettered on the stake. The station numbers should be written on the back of the stake.

The work of staking out is usually done by from three to five men with a level, rod, tape, and ax. The work is exceedingly simple, though difficult to explain clearly. The only thing difficult to comprehend is the method of finding the proper position for the slope stakes. Let the section of Fig. 91 be considered. The elevation of the grade level at any station will be known from the profile. The level of the ground at A will also be known from the profile or the location level book, but is usually redetermined for a check when the work is staked out. The difference between the ground and grade levels is the fill C, which, when found, is recorded in the note-book and written on the stake. The level being set up within reach of the section shown, and the height of instrument determined from a neighboring bench mark, a rod is held and read at A, giving the elevation of A and hence, by computation, C. After the record is made the rodman or instrument man, or both, estimates the distance d_r, the rod is taken out the estimated distance and read, and a value for h_r determined. With this value of h_r a computation is made to see if d_r was correctly estimated; if found correct, a stake is marked and driven, and the values h_r and d_r recorded in the note-book. If found incorrect, a second estimate is made, and the operation

repeated till the estimated distance and computed distance agree, when the stake is marked and the record made. The distance d_r depends for its value on h_r, and is found thus: Considering Fig. 91 as before, $d_r = \frac{1}{2}w + m$; if S be the slope ratio, that is, horizontal to vertical, or $S = \frac{m}{h_r}$, then $m = Sh_r$ and $d_r = \frac{1}{2}w + Sh_r$. If the first estimate of d_r should give the point E′, the value of h from the rod reading there would give a value for d_r, greater than estimated, and if the first estimate gives the point E″, the value of h from the rod reading there would give d_r smaller than estimated, and according as the result is one way or the other the second estimate will be made greater or less than the first. After one side is staked the operation is repeated on the other side. The first estimate of a distance d is often near enough to the truth, when made by an experienced man. He makes his estimate by knowing C, from this estimating h, and then computing d. S and w would always be known; thus, w, is usually from 14 to 20 feet for single track road-bed, and is determined for any particular road before building. S depends on the material, but is also usually specified for any particular road for the various classes of material to be met with in the construction. It is usually three halves, or, as spoken, 1½ to 1. Most army engineers give the slope by mentioning the vertical first, as 1 on 1½, and this ratio is that used by French engineers. In the side hill section, Figs. 95 and 97, the point G is found by trial, moving the rod from the center toward one side till the point is reached where the rod reading is what it should be for the grade level.

Grade Level *vs.* Datum. — In doing this work it is best to carry the height of instrument above grade rather than above the

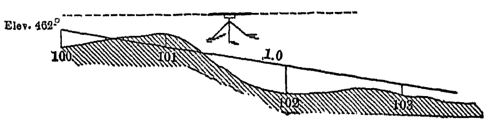


Fig. 98

assumed datum, as the rod reading more quickly gives the fill or cut. Thus, suppose Fig. 98 to represent a short section of profile show-

ing a grade line elevation of 462.0 at station 100, and a descending 1 per cent grade. The center line is evidently in fill between station 100 and about 100 + 60, is in cut at station 101, at grade at about 101 + 25, in fill at 102, etc. Suppose the instrument set up with an *H.I.* of 465.2, then at station 100 it is 3.2 above grade, and the difference between this and the rod reading gives the fill. The grade falls a foot to 101, hence *H.I.* above grade at 101 is 4.2, and the difference between this and the rod reading is the cut. Finding cut at 101 by noting that the rod reading is less than the *H.I.* above grade, a trial is made between 100 and 101 to find the grade point; at + 60 the *H.I.* above grade is 3.2 + 0.6 = 3.8, which being the rod reading shows grade to be at this point, and a grade plug is driven. Other near-by cross-section may be taken or not according to the magnitude of the work, as explained below. At 101 + 25 *H.I.* above grade is 4.2 + 0.25, and a grade point is looked for, if the reading is not just 4.45 grade is nearer or farther from 101, possibly at + 30, where the *H.I.* above grade is 4.2 + 0.3 = 4.5. At 102 *H.I.* above grade is 5.2, etc., until the capacity of the rod, or distance limit of the instrument, is reached. If the instrument were below grade, as in staking out a high fill, the *H.I.* *below* grade, plus the rod reading, would be the fill. A set rule could be formulated for determining whether the rod reading indicated cut or fill, but such rules are believed to be unwise; the engineer should be clear in his own mind from his own reasoning in all that he does.

Terminal Pyramid. — When the work passes from fill to cut on a hillside so that the grade contour runs diagonally across the road-bed, and the fill and cut road-beds are of different widths, the cross-section notes to be taken may be made clear by an inspection of Fig. 99. The pyramid of embankment DBHF may be known if the area BHF and the distance HD are known, and the pyramid of cut is known when the area EJG and the length AJ are known. Hence the notes will show

1. The station and plus of A, point where grade is first found at the cut half road-bed out.

2. A cross-section of the fill at B, with its station and plus.

3. The station and plus of D, point where grade is last found at fill half road-bed out.

4. A cross-section of the cut at E, where the work begins to be wholly in excavation, its station and plus.

It is usual also to find the point C and set a grade plug there, recording the station and plus.

If the work is light, or the grade contour crosses the road-bed nearly at right angles, only the point C need be found or recorded,

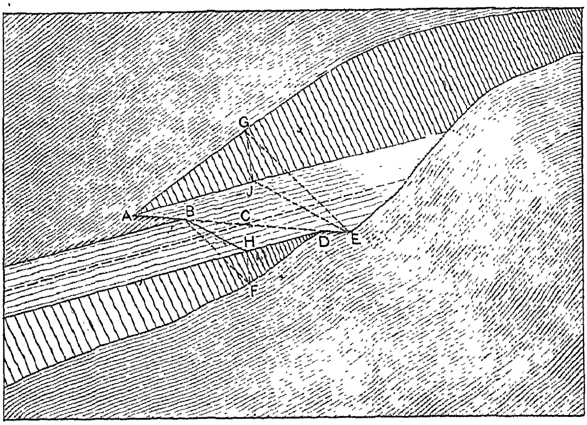


Fig. 99

the fill and cut being considered to end and begin here with zero areas.

Compound Sections. — Occasionally borings indicate that the first few feet in depth of a cutting is earth and the rest rock. The rock being taken out at a steep slope, the top width would be too great if staked out on the assumption that the cut is earth and too narrow if on the assumption that it is rock. The compound section is staked out as follows, referring to Fig. 100. Soundings show the depth of C_e and leveling shows C_e plus C_r. If the rock is to be taken out with vertical sides the width of cutting at the top of the rock will be w, and allowing an arbitrary berme width of 6 feet between the edge of the rock cutting and the bottom of the earth cutting gives a base width of $w^1 = w + 12$ for

the earth portion, and this is used as w in staking out the cut. When the rock is reached, new staking is had for the lower part of the cut. The assumption has been made above that the rock surface is level across the line. It will do no material harm to assume this unless there are indications that

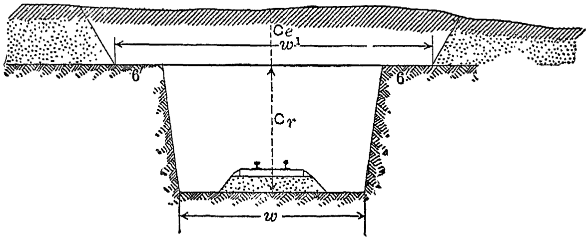


Fig. 100

it is considerably at variance with the true condition. When side borings as well as center borings are made, a probable cross profile of rock and actual cross profile of surface may be made, a section drawn to scale, and the positions of slope stakes taken to scale from the drawing.

Embankment Toes and Borrow Pits. — To stake out a bank toe when the end of an embankment joins a trestle or pile bridge,

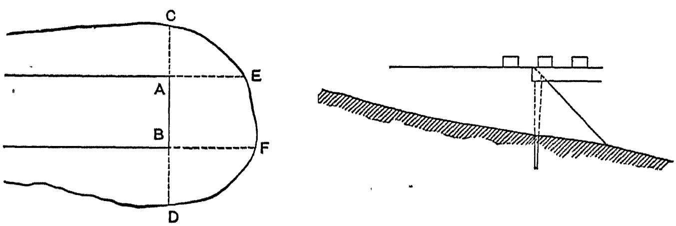


Fig. 101

heights are determined at the lettered points of Fig. 101 and distances from center out to C and D, and from A and B to E and F, respectively.

Borrow pits are staked on fairly level ground by marking the

edges opposite each station and taking cross-sections at these stations before and after the excavation to derive the volume moved. Sections may be taken oftener than each station if found desirable. If the borrow pits are on a side hill, or are lateral extensions of regular cuts, the volumes moved may be obtained by taking cross-sections before and after excavation at such intervals as may be deemed necessary.

Staking out Culverts. — A simple box culvert is staked out by putting two stakes centered with tacks on the center line of the road, one on either side of the pit to be dug for the culvert foundation, two stakes centered with tacks to mark the center line of the culvert, one a little beyond either end, and four stakes to mark the corners of the foundation pit. The last four stakes are not centered, but are marked with the depth of cut to the pit bottom. If apron stones are to be put below the general level of the foundation, the cut is not given on the stakes to the bottom of the apron stone, but to the general level of foundation. The engineer determines from the culvert plan and the elevation of the ground what the depth of foundation is to be. The culvert will always be given a slope, usually about the average of the stream slope. A diagram will be given the builder showing length from the center line of the road up stream and down, and he will have general plans from which to build.

An arch culvert with battered walls, and wing walls, and an opening, will usually have each wall staked separately, the cross line being the projection downward of the line at the springing of the arch, or the line under the coping. The offset from this to the parallel line at the foot of the main wall above the footing course will be computed from the height of the wall and the batter, and some engineers lay this line instead of that under the coping. With flared wing walls the better practice is to lay out the line of the foot of the walls. When the structure is of some magnitude and the foundation pit deep, considerable allowance must be made in laying out the pit outside the neat footing course or foundation walls for a slope to the sides of the pit, for coffer dam thickness in wet ground or water, and for room to work on the face of

the wall between it and the sides of the pit. Approximate depth of foundation is determined by sounding. For simple cases, a steel rod, or gas pipe, driven with a hammer, answers. For important structures and difficult foundations a test pit may be necessary, and always the soundings should cover fairly the area of the bottom of the pit. A single sounding on center line tells nothing; the rod may strike a boulder, the rock may have a sharp, irregular dip. In a simple case stakes should be set at the corners of the pit and marked with the depth of cutting, determined by the engineer.

Simple arch culverts of small dimensions, and pipe culverts, will be staked out just as box culverts are.

Staking out Trestle and Pile Bridges. — Trestles are staked out by giving the center line at the beginning and end of the bridge, and as frequently between as the length of the bridge and the desire of the builder makes necessary, and the elevation of the foundation level (bottom of sill) and grade level at each bent, for the framing of the bent. If preferred by the builder, the engineer may give the height of bent, and if on a curve, the height at the center and the inclination of the cap. He will also give the grade of foundation when the builder is ready to prepare it.

Pile bridges will be staked by giving the center line at both ends, and, if possible, between, at as many points as may be required. Soundings will be taken before the piles are driven to indicate the probable length of pile necessary. Tacks or nails for cutting off will be set on as many piles of each bent as the builder desires; marks on the two outside piles are usually sufficient, and they may be set one foot or other arbitrary distance below the cutting off level. The points are found by the use of the level and rod, the data being the grade shown on the profile, and dimensions found on the plan of the structure.

Staking out Tunnels. — Setting the line for short tunnels is not difficult; setting the line for long tunnels piercing a mountain range may be very difficult, not in the way of theoretical problems, but in the extreme care that must be taken to insure the meeting of the two headings driven from opposite ends or from shafts

sunk on the tunnel line, and the difficulty of working in the dark, wet, and cramped passages.

If the tunnel is short, the center line, be it straight or curved, is carried over the hill with great care and produced into the tunnel from both sides. The nature of the hill or bluff may make it practically impossible to carry the line directly over, when the tunnel may be driven from one end, or a random traverse may be run by any possible route from one side to the other, the necessary computations made to determine the proper point and direction on the farther side. It is believed that the student familiar with ordinary surveying methods can devise such plan as may be necessary in any case.

A long tunnel is usually straight, though some have a curve near one end. When this is the case the tunnel may be run straight at first, then enlarged to the curve if not too long. The only reason for not driving the tunnel at once on the curved line is the greater difficulty of laying out a curve and tangent with the precision of a single straight line. For projecting the line across the mountain, permanent piers should be established at intervals on the line, and centers determined on these piers by repeated double centering with a large instrument. An adjustable centering piece may be devised, sliding in a frame by opposing screws, permanently fixed when the final position has been determined. If high hills lie opposite the tunnel portals, additional stations may be placed on these for reference as indi-

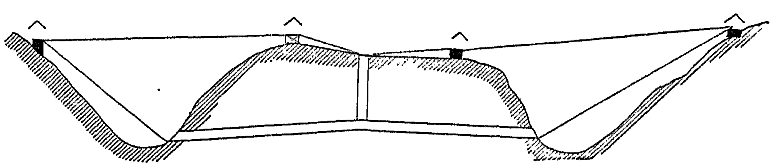


Fig. 102

cated in the sketch, Fig. 102. They make the projection of the line across the mountain easier and more certain than a line carried up the steep, irregular sides above the ends of the tunnel. In any important work the station piers will be housed in. If the distances are long, a large transit with a telescope having at least

a 2-inch objective aperture and corresponding magnifying power, should be used. The line must be carried many times into the tunnel to insure precision. Stations in the tunnel may be made by drilling holes in the roof, inserting wooden plugs, and driving line nails in these. Line nails may be like horseshoe nails with a round or triangular hole in the head for suspending a plumb line. In some long tunnels, even in rock, the roof moves, due to the great pressure of the mass above, and no permanent marks can be made till the tunnel lining is in place. Temporary marks may be made in the caps of the timbering in tunnels through earth or soft material. A plumb bob may be suspended from the roof station point and the string, illuminated by a candle or lamp, will serve as a flag. When the instrument is to be set at the station, a temporary point may be set on the ground or a small hole in the center of the telescope tube may be centered under the station mark with a plumb bob. A system of tripods with interchangeable transit and lamp target heads may be used to advantage as in mining. The back and fore sight stations will be occupied with a tripod and lamp target, the observing station by tripod and transit. When ready to move ahead the back tripod will be taken to the forward station, its lamp being left on the instrument tripod, while the instrument replaces the lamp on the forward tripod, which lamp is again moved forward to the new position of the third tripod.

When the depth of the hill or mountain penetrated is not too great, the progress of the work is increased by sinking one or more shafts. The line of the tunnel is determined at these shafts by suspending two plumb lines, both in line, one on each side of the shaft. The excavation is directed at first by the line joining the two hanging plummets and, after it has progressed sufficiently to permit, by a transit set by trial in line with the two swinging bobs. If the plumb lines are very long, more than one or two hundred feet, fine piano wire is used for the lines, and heavy bobs varying from 5 to 25 pounds according to the depth of the shaft. Air currents will prevent the bobs from hanging perfectly still. The mean position of the vibrating bob must be

taken. The vibrations are lessened by putting the bobs in vessels of water or oil, or even less fluid liquids — as molasses. Various devices have been used for exactly centering the lines at the top of the shaft. The engineer will be able to devise some means. For great precision he must provide for lateral motion of the wire by screws. Tunnels are usually on a grade, and the leveling must be as carefully done as the line work, that the two headings may come together properly in vertical as well as horizontal alignment. A long tunnel being usually a summit, should have grades ascending from both ends to the middle, or a point near the middle to provide for proper drainage during construction; a short tunnel, being frequently a cut through a narrow projecting ridge, may be on a continuous grade. When very long tunnels are on a continuous grade, air must be pumped into both ends, and water pumped out of the higher end.*

Bridge Surveys. — Bridge surveys include making soundings for foundations, locating these soundings on a large scale map of the site, and the location of abutments and piers.

The soundings are made in ordinary cases with steel rods driven with hammers; or with gas pipe sunk by blows or by a jet of water forced through the pipe which is churned or weighted, as may be necessary; or in important cases, by the use of heavy pipe and light pile driver with or without the use of a water jet; or with diamond or other drills that bring up a core of the material penetrated.

Except in cases where the character of the foundation is evident from the surroundings, single soundings on the center line at proposed abutment and pier points should not be permitted to suffice. A single sounding tells nothing; apparent rock may be a boulder; the rock may pitch irregularly or break off where least expected. Some costly errors have been made as the result of insufficient sounding for foundations. For important structures

* For details of alignment, design, construction, cost, etc., see "Tunnelling," by Simms, "Tunnelling," by Prelini, and articles in the engineering press on the Simplon Tunnel, The Detroit River Tunnel, The Pennsylvania Railroad's Hudson River Tunnel, The New York Subway, and The Boston Subway, and the Reports of the Boston Subway Commission, the New York Rapid Transit Commission, etc.

enough soundings should be taken to insure a correct knowledge of the character of the bottom and its slope over the whole area to be occupied by pier or abutment.

In surveys preliminary to the planning of an important bridge, soundings should be taken at frequent intervals along three lines, the center line and two parallel lines up and down stream respectively.

The soundings in the stream may be made from an anchored boat, and the points located by triangulation on the shore.

It is best, whenever possible, to locate pier centers by direct measurement with long steel tapes, supported if necessary by intermediate boats. When this is impracticable pier centers may be located by triangulation from shore. For long spans this work requires great care, both in measuring a base line and in calculating and turning the angles.

Remembering that an error of one minute in turning an angle means an error in position of about $\frac{3}{8}$ of an inch for each 100 feet of length of the line along which the sight is taken, and that this error is increased in the location of the point of intersection, the necessity for close angle work is evident. An instrument reading to 20 seconds is desirable for this work, and two triangles should be used when possible for a check, one lying up stream and one down stream from the center line. There will always be two sides and the included angle known to find and lay off a second angle. Well-conditioned triangles should be used; the best is one that is approximately an equilateral triangle, and none should be used having any angle less than about 40 degrees. In general one angle of each triangle will be a right angle.

Classification. — Classification of earthwork is one of the troublesome features of the work of a residency. Specifications usually provide for three classes of work, — solid rock, loose rock, other excavation, sometimes called common excavation, sometimes earth. Formerly a fourth class was common, namely, hard pan or hard material. A not unusual specification for this was "material that cannot be excavated with a strong grading plow well handled and drawn by a team of six horses or mules, but that

does not require blasting, though blasting may be resorted to." A moment's consideration will show the indefiniteness of this specification; there are all kinds and sizes of horses and mules; there are all kinds of plowing, from scratching the surface to deep furrows over the share; there are all sorts of plowmen, honest and dishonest, capable and incapable; and there is always a difference in judgment of two men trying to be fair, one prejudiced by his financial interest in the contract, the other by his allegiance to the employing company.

Some specifications have gone so far as to recognize but two classes of earthwork, solid rock and earth, the former being "solid ledge rock in place, requiring blasting for its removal," the latter being "all other excavation, including ledge rock, that may be barred out, and boulders of no matter how large dimensions."

This specification is comparatively easy of interpretation and application, and in some localities would be fair; but it is submitted that specifications should not be copied one from another with no reference to the geological formation along the line to be built. Specifications should be adapted to the character of the work likely to be met, and may indeed vary for different parts of a long line stretching across smooth plains and rugged mountains. It is a common practice that sometimes results satisfactorily and sometimes leads to disputes and litigation, to classify a material that falls strictly under common or earth excavation, but that by reason of its peculiar character, as hard cemented gravel, costs more to move than any ordinary earth, often more than loose rock, as containing a percentage of loose rock or solid rock, as the case may be. The percentage is assigned by judgment or by determining the actual cost of the work, and using this with an assumed profit to determine the price that should fairly be paid and the consequent percentage of higher classification.

Contracts are frequently let before the line is finally located, and this practice, to be condemned in the case of short branch or other lines, is justified in the case of long lines by the financial necessity for quick construction, and the wisdom of letting large contracts to men or companies of strong financial standing who

would not be interested in small contracts of short portions of the line that might be let from time to time as the location is completed. A general contract for a long line not yet located must contain clauses covering unexpected or unknown contingencies.

It is submitted that the general specification should provide for the contingency of material not fairly falling within the letter of the adopted classifications, and should leave the determination of the price to be paid for such material to the engineer of the company. It is to be assumed that he is both honest and fair, and his records under such a contingency clause could be clear and intelligible to any officer or court.

The introduction of a contingency clause for classification should in no wise lessen the care used in formulating the specifications for the regularly adopted classifications. These should be clear, simple, and complete.*

Haul. — The subject of haul or overhaul is one on which a wide difference of opinion exists.† Specifications usually provide that the contract price for excavation shall include payment for excavating the material, hauling it, and placing it in embankment or elsewhere as may be directed. It is usually further provided that if the material must be hauled beyond a specified distance — varying from 500 to 2000 feet, sometimes to two or more miles where the haul is by train — an extra price will be paid for material so overhauled at a rate of from $\frac{1}{2}$ cent to 1 cent a cubic yard for each 100 feet of haul in excess of the specified so-called free haul.

The specification should be explicit as to the method of determining the overhaul (quantity times distance overhauled), and the following is suggested as fair and clear: —

Overhaul shall be determined as follows for adjacent excavation and embankment: 1. The positions of two vertical planes separated by the free haul limit of ______ feet will be found, between

* For specification forms see "Manual of Recommended Practice," American Railway Engineering and Maintenance of Way Association.

† A full discussion of the numerous practices, and a review of the literature of the subject will be found in the Proceedings of the Seventh Annual Convention of the American Railway Engineering and Maintenance of Way Association, 1906.

which planes the volume of excavation, with due allowance for shrinkage or increase, equals the volume of embankment. 2. The positions of two vertical planes, one through the excavation and one through the embankment, shall be found such that the volumes of adjacent excavation and embankment between them are equal, with due allowance for shrinkage or increase from excavation to embankment, and including between them a volume of excavation equal to the whole volume moved from the particular excavation to the particular embankment. 3. The positions of the vertical planes through the centers of gravity of the portions of embankment and excavation respectively included between the second two planes and not included between the first two, shall be found; the excess of horizontal distance between these two center of gravity planes over and above the free haul distance of ______ feet shall be reduced to stations of 100 feet, and the resulting number, multiplied by the number of cubic yards in that portion of the excavation whose center of gravity vertical has been found, shall give the number of overhaul units on which payment at the rate of ______ cents per unit shall be made.

The foregoing could be simplified by reference to a figure that might be drawn and zincographed for introduction in the specifications. While the description contains more words than are necessary to use in explaining the method to one who wishes to understand, a statement of procedure in a specification should be so full and complete as to make possible but one interpretation by a court, and that interpretation the original intent of the specification.

When a contract is not to be let till the location is complete, a mass diagram should be constructed, the disposition of all material determined, and the contract let with this full information without any overhaul clause except one providing that there shall be no overhaul, and that the contract price covers all hauling required. When a general contract is let for a long line in advance of location, an overhaul clause is a necessity as a matter of economy, since if all the chances that are to be taken are put upon the contractor, the result will be a high unit price for the work.

CHAPTER XXII

BETTERMENT SURVEYS

Object. — Betterment surveys may or may not be surveys at all. The engineer's object in the betterment of a railroad is increased capacity for and reduced cost of handling traffic. There are other reasons for bettering the service in various ways, but with these the engineer, as an engineer, is not concerned. The defects — or rather possibilities of improvement — are so various with different lines that it is not practicable to set out any hard-and-fast rules of procedure. A few suggestions can be offered.

Velocity Profile and Power Curves. — After obvious improvements have been recognized, the first thing to do is to make a velocity profile for each division for the maximum train of each class — slow freight and fast freight — and horse-power curves of the several locomotives used. To do this each locomotive is loaded by trial with the maximum train it can haul at minimum speed on the *de facto* ruling grade of its division and sent over the road at the best speed it can make with safety. Indicator diagrams are taken from the cylinders, the draw-bar pull is measured with a dynamometer car, and the speed is graphically recorded on a continuous sheet by the mechanism of the dynamometer car. The steam pressure, cut-off, and throttle are watched and regulated by trial to give the best possible results. The velocity heads are computed for as many points as desired, plotted on the profile, and their tops connected for the velocity profile. The tractive effort of the locomotive is plotted on a diagram of axes speed and tractive effort.

Locomotive Distribution. — The locomotive horse-power diagrams will be studied to determine whether the locomotives are distributed on the several divisions to the best advantage. Two or more locomotives of equal weight will be found to vary in the

speed at which their maximum power is developed. If two divisions of the same ruling grade have, respectively, short undulating grades and long and continuous grades against the heavy traffic, the locomotive developing its maximum effort only at low speed is suited to the division of continuous grade, while that one developing its maximum power at high speed is best suited to the division of undulating grade.

Economical Speed. — Before undertaking expensive grading or relocation for grade reduction, the best that can be done with what is should be discovered and adopted. Besides the redistribution of locomotives, the most economical speed for each class should be determined. It has been shown that there is no such thing in general as the most economic speed. There is a most economic speed for each type of locomotive in each direction on each division of any railroad. This most economic speed is the fastest average speed that the given locomotive can safely make over the entire division hauling the greatest load it can move at the lowest practicable speed on the steepest *de facto* grade of the division.

For slow-moving freight the proper load for a locomotive is the greatest it can haul at the minimum practicable speed on the steepest *de facto* grade. For fast freight trains the proper load is the greatest load that can be hauled on the steepest *de facto* grade at a speed that will permit the making of the necessary schedule over the line if the highest speed possible and safe is made on the remainder of the division. The foregoing statements are true, subject to the limitation of a practicable train length.

Changing Division Point. — On long lines a change of division point may be wise. Thus the characteristics of a division on which a given locomotive can haul fifty cars may extend several miles into the next division through the remainder of which the same locomotive can haul but thirty or forty cars. If this portion of the second division can be included in the first, a good many train miles may be saved. Whether this will be profitable depends on the cost of moving the division point — almost always

a considerable item — and whether water and other supplies are as cheaply and conveniently obtained at the desired new location. It is not necessary that the crew division shall correspond with the locomotive division, but it is convenient to have this correspondence.

Velocity Profile Indications. — The velocity profile will show the location and rate of the real ruling grades and the places where the greatest reduction in real ruling grade can be made for the least expenditure. What reductions are profitable will be determined by offsetting the reduction in operating expenses due to fewer and heavier trains against the interest on the estimated cost of the necessary improvements to secure the reduced grades and greater train load.

The velocity profile may show that a stopping point in a grade hollow, or several such stations, actually limits the load that can be hauled, rather than the supposed ruling grade. Not infrequently an inconsiderable movement of the station points for freight trains, or a grading up of the freight yard to form small summits, may increase the train load over the whole division by converting a limiting grade out of a stopping-point into a momentum or velocity grade that may be safely operated as a lower grade than the profile shows or than has been before possible.

The great value of the elimination of grade crossings that occur in sags will appear.

A pusher engine may be in service on an undulating grade and necessary only on the steeper portions. If two or three points can be lowered a little the train might be handled by a single engine, or might be so handled if reduced by one or two cars, still saving a considerable number of engine miles. On the other hand one or two limiting summits may appear, the operation of which by pusher engines would materially increase the train load over the division. The possibilities of the next lower ruling grade will then be investigated and the cost of operating the pushers will be set against the saving in trains due to the greater train load.

A continuation of a second track for a short distance may avoid

the occasional stopping of a heavy train on an adverse grade for the passing of a light train down the hill. The location of the second track may even be on a slightly different alignment, giving better grades.

Simple Method. — It is not always necessary to indicate the locomotive and use a dynamometer car in grade investigations. The application of the principles of Part II of this book will enable the engineer to determine pretty closely what to expect of a given locomotive on a given profile, and simply riding over the division, watching the pressure, cut-off, and throttle, and taking the speed from an indicator that may be attached to an axle of the caboose, or even counting telegraph poles at critical points, or revolutions of the drivers at these points, will frequently furnish all the information necessary to the investigation. The more careful and complete records of the indicators and the dynamometer car are essential to the road tests of the locomotive for the purposes of the motive power department, but are not always essential to the study of grade revision.

Relocation. — Relocation of the line for elimination of rise and fall, curvature and distance, and the reduction of grade, may be advisable, and many such relocations have been made. Other questions than the cost of operating curvature, rise and fall, distance, etc., enter to determine the advisability of such relocations. The demand for high speed is increasing as fast as the railroad can create it. There is no demand on the part of the public for any speed that is not entirely safe and economical. The fact that a given railroad finds patronage for an excessively high speed train is no evidence of a demand for such a train. Nevertheless, in the recent past it has been deemed advisable by many companies to spend large sums in the elimination of curvature that was not seriously objectionable except to fast trains. A straight road appeals to the public as a safe road, but a crooked road is more frequently a picturesque line. The matter of large expenditures for the elimination of the minor details of curvature, rise and fall, and distance, is one that must be determined as a question of policy rather than a question of actual cost. Still,

the value of the elimination of these items should be obtained as carefully as possible, and offset against the cost of the necessary work.

Relocation that abandons established stopping points is not always possible, and when not possible, the cost of operating the existing line for such distances and with such trains as may be necessary must be offset against the value of the proposed improved line.

Improvement Gradual. — It is not often possible for desirable improvements to be undertaken all at once. The work will be done from year to year as money may be available. It is then to be determined what shall be done first and what the order of improvement shall be to accomplish the most at the earliest possible day.

Conclusion. — Railroad location has been in the past an inviting field for engineering effort, and yet the greater portion of the trunk lines of the country were located and constructed before the principles that should govern location were well understood. For this reason, and also because in days of light traffic it was the good practice it seemed to be to build the cheapest feasible line, there are few lines in operation now that show no possibility of improvement in line and grade. The study of an operating line with a view to increasing its efficiency is a most fascinating occupation, and one demanding a high order of intelligence.

APPENDIX

THE LOCATION OF THE KNOXVILLE, LA FOLLETTE AND JELLICO RAILROAD, OF THE LOUISVILLE AND NASHVILLE SYSTEM.*

By W. D. Taylor, M. Am. Soc. C. E.

With Discussion by Messrs. Emile Low, William P. Watson, E. J. Beard, Walter Watson, William G. Raymond, F. Lavis, W. H. Coverdale, and W. D. Taylor.

There are experienced field engineers to whom the perusal of this paper will be a loss of time. Many engineering papers deal with the special characteristics of special structures, to the exclusion of broader questions. The experienced engineer spends most of his time in thinking out the details of such structures, and, when he writes an account of his work, assumes that his readers will grasp at once the broader questions involved, and will be interested only in the special designs which have taxed his own ingenuity most. This would be all very well if his writing fell only under the eyes of experienced readers; but, probably, ten inexperienced readers, ten students, perhaps in search of information, will read his article carefully where one busy and experienced engineer gives it hasty perusal. For the inexperienced reader, the broad questions affecting the whole proposition are oftentimes of more value than a minute description of the details of special structures. For him a discussion of the eco-

* From Transactions American Society of Civil Engineers, Vol. LII. Discussions by Mr. Harvey Linton and Mr. W. D. Forsythe, and portions of other discussions have been omitted in this reproduction, and paging references have been changed to fit the paging of this book.

nomic questions which determined that the whole project of construction was advisable may be of more importance than the most intricate and learned calculation upon the strength or efficiency of special structural parts; or, to be still more specific, the reasons for building a road in one valley rather than in another offering a shorter route may be more instructive to the majority of readers than any or all of the detailed masonry plans worked out in the construction of the road. In this paper the writer has attempted to set forth the considerations which determined each important step in the lay-out of what he believes is the most important engineering work undertaken in recent years in the section of country in which this road lies. The paper does not even mention the part of the work on which the writer spent most of his force; but, in his judgment, it includes an account of all the best work accomplished on this undertaking, both by himself and by those working over and under him.

In March, 1902, the writer was tendered the position of engineer of construction of the Knoxville, La Follette and Jellico Railroad, with the assurance that the line was to be constructed "through difficult country."

The Louisville and Nashville Railroad Company has a line from Cincinnati to Jellico and from Louisville to Jellico (Fig. 103). At this time, the company had just acquired control of the Atlanta, Knoxville and Northern Railroad. For some years previous, it had operated the Georgia Railroad under a joint lease with another company. For a long while, it had had a large, if not a controlling, interest in the Atlanta and West Point Railroad and in the Western Railway of Alabama. Thus the system was in entire or partial control of some 900 miles of road to the south of Knoxville, with which it had direct connection only at Montgomery, and connection through a controlled road at Atlanta. From Fig. 103 it will be seen that, in order to have these properties closely united to the body of the system, as well as to operate through trains from Cincinnati and Louisville through Knoxville to Atlanta, the construction of the gap from Jellico to Knoxville was necessary.

The order for the survey and construction of the line was not accompanied by any of the usual tentative conditions. A fair traffic could be safely counted on for the new line, from the day of its completion, without considering the large local traffic which could probably be developed along the route. Thus the chief executive of the

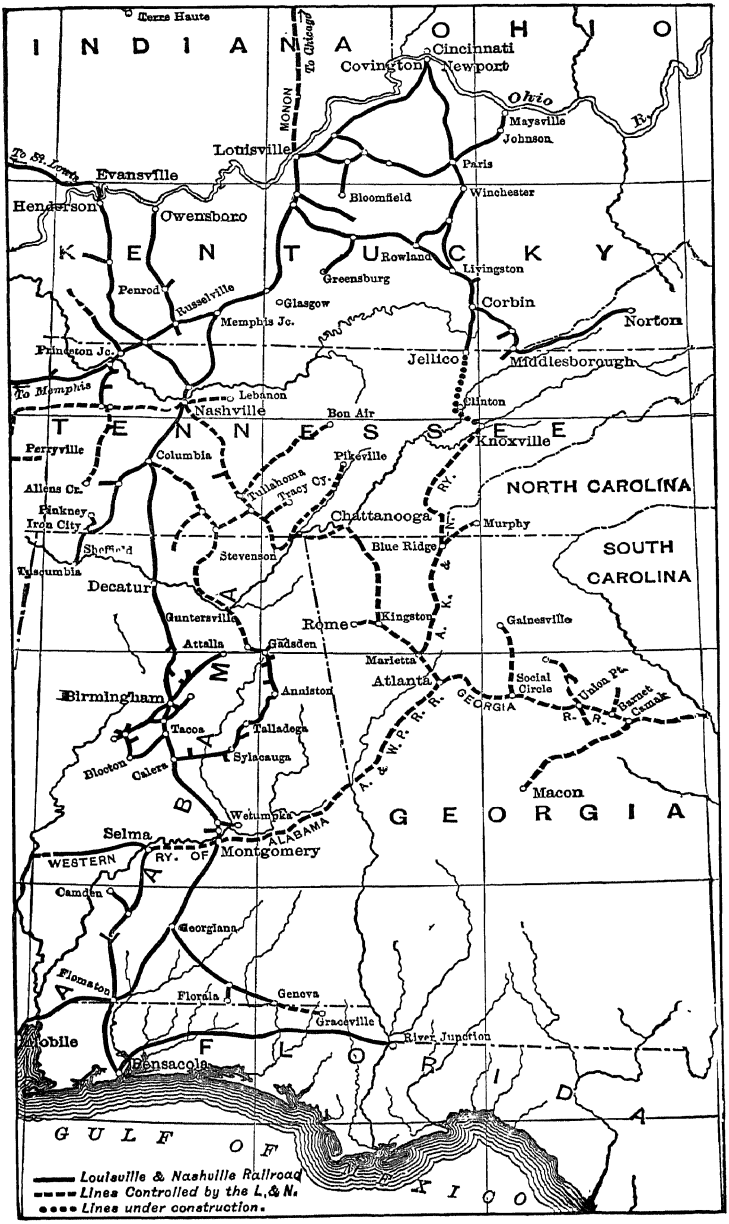

INDIANA
OHIO
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
FLORIDA
GULF OF MEXICO
Terre Haute
To Chicago
MONON
Cincinnati
Covington
Newport
Ohio
R.
Maysville
Johnson
Paris
Louisville
To St. Louis
Evansville
Henderson
Owensboro
Bloomfield
Winchester
Rowland
Greensburg
Livingston
Corbin
Norton
Penrod
Russellville
Glasgow
Memphis Jc.
Princeton Jc.
Jellico
Middlesborough
To Memphis
Lebanon
Nashville
Clinton
Bon Air
Knoxville
Perryville
Columbia
Pikeville
Allens Cr.
Tullahoma
Tracy Cy.
Pinkney
Iron City
Chattanooga
Murphy
Sheffield
Stevenson
Blue Ridge
Tuscumbia
Decatur
Guntersville
Rome
Kingston
Gainesville
Attalla
Gadsden
Marietta
Atlanta
Social Circle
Union Pt.
Barnet
Camak
Birmingham
Anniston
GEORGIA R. R.
Tacoa
Talladega
Sylacauga
Blocton
Calera
A. & W. P. R. R.
A. K. & N. RY.
Macon
Wetumpka
Selma
ALABAMA
WESTERN RY. OF
Montgomery
Camden
Georgiana
Flomaton
Florala
Geneva
Graceville
River Junction
Mobile
Pensacola
Louisville & Nashville Railroad
Lines Controlled by the L.& N.
Lines under construction.

Fig. 103.

road was warranted in authorizing expensive construction, if need be, to secure good grades and alignment.

The distance from Saxton, Kentucky, to Knoxville, Tennessee (see Fig. 104), on a straight line, is approximately 51 miles; *via* the Louisville and Nashville to Jellico, and the Knoxville and Ohio Branch of the Southern from Jellico to Knoxville, it is 68.3 miles. This branch of the Southern was built years ago, when, in the location of railways, little attention was paid to future economy in operation. The line, in places, has grades of 93 feet to the mile, uncompensated over stiff curves, even near the tops of long ascents. Helper engines are used freely on the line even on passenger trains. But the traffic in south-bound bituminous coal, from Jellico, Pioneer, La Follette, Coal Creek, Briceville and Oliver Springs, is large enough, it is said, to make this one of the best paying lines of that system.

The entire country between Saxton and Knoxville has been covered by the United States Geological Survey, and the maps of this Survey, though found to be very inaccurate as regards topography in a country inaccessible by horse or wagon, were of untold value in choosing the routes for the line.

Waldens Ridge and Cumberland Mountain (Fig. 104) divide the district into two parts, unlike in geography, topography, and geology. That portion of the country to the northwest of this ridge and mountain is part of the Cumberland plateau of the Appalachian province. The drainage, for the most part, is to the north and northwest into the Cumberland River. The portion of the district to the southeast of this divide is a part of the great valley of East Tennesse, and the general drainage is to the southwest into the Clinch and Tennessee Rivers. To the northwest of this dividing line, the surface rocks are Carboniferous; to the southeast they are Cambrian and Silurian. The country to the northwest of this line is so broken and rugged that it may be called the mountain district. Here the divides rise to elevations of from 2500 to 3600 feet, large areas being above 3000 feet. The streams fall rapidly, from their sources, and emerge into the valleys at elevations of from 800 to 1100 feet. These valleys are deep and narrow, and the slopes rise brokenly. The crests of the mountains are narrow and flat, many of them being susceptible of cultivation; but, so far, the steep and rugged slopes have proved to be effectual barriers to the settlement of the district, except by the scattered cabins of mountaineers. There are homes in these mountains which have

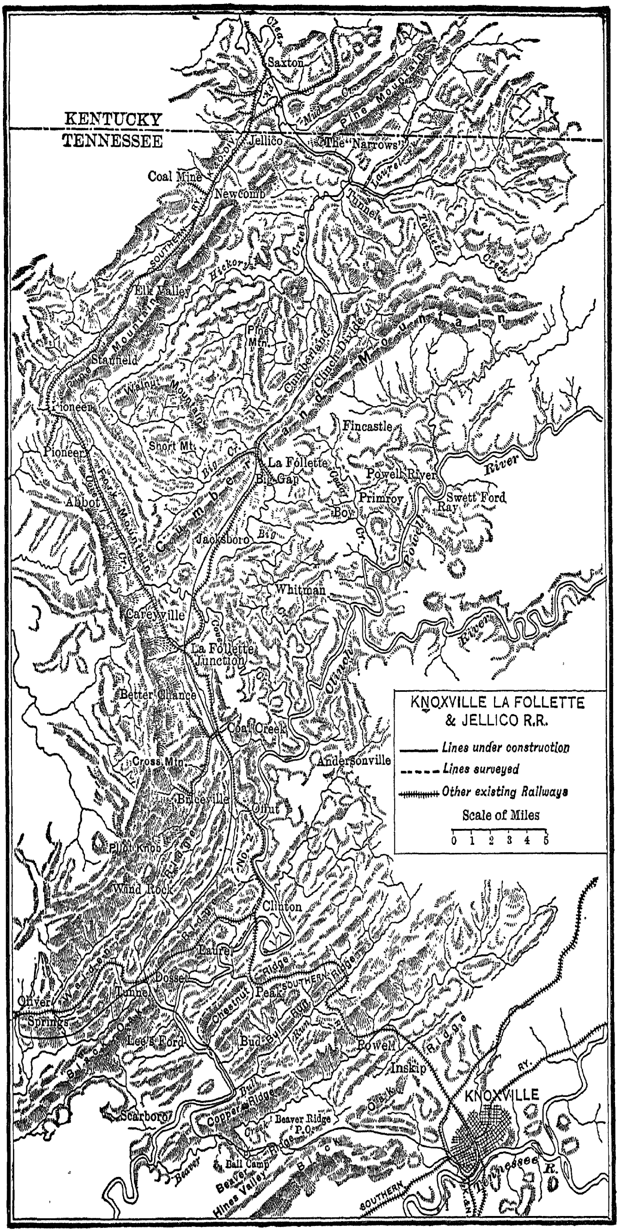

KENTUCKY
TENNESSEE
Saxton
Jellico
The "Narrows"
Coal Mine
Newcomb
Tunnel
Elk Valley
Stanfield
Pioneer
Pioneer
Fincastle
La Follette
Big Gap
Powell River
Primroy
Swett Ford
Ray
Abbot
Jacksboro
Whitman
Careyville
La Follette Junction
Better Chance
Coal Creek
Cross Mtn.
Andersonville
Briceville
Offut
Pilot Knob
Wind Rock
Clinton
Laurel
Dossett
Tunbo
Oliver Springs
Peak
Lee's Ford
Bud
Powell
Inskip
KNOXVILLE
Scarboro
Beaver Ridge P.O.
Ball Camp
Hines Valley
SOUTHERN
Tennessee R.
KNOXVILLE LA FOLLETTE & JELLICO R.R.
Lines under construction
Lines surveyed
Other existing Railways
Scale of Miles
0 1 2 3 4 5

Fig. 104.

been occupied for generations, with no wheeled vehicle ever in use until roads were opened by the contractors for the construction of this railroad. The mountain ranges are cut in two by occasional streams, and thus all possible routes on reasonable gradients are well defined.

In the valley district, erosion has produced a series of long ridges separated by long, parallel and narrow valleys which follow closely the belts of rock. Their general direction is northeast and southwest, thus crossing the direction of the line of survey, which lay somewhat northwest and southeast. The surfaces of these small valleys are at elevations of from 800 to 1100 feet, and the parallel ridges rise from 100 to 500 feet above them. Some few of these ridges are cut in two by streams, but most of them are continuous for many miles. Copper Ridge, on the south side of the Clinch, which ridge is responsible for the second large détour to the westward in the line of road between Coal Creek and Knoxville, was such a continuous ridge. From the point where the road cuts through it, for 30 miles to the northeast, there is not a gap in which the crest is not more than 350 feet above Bull Run Valley on the north side of it. The conditions as to continuity were somewhat similar in the case of the two Black Oak Ridges. Thus the problem of getting the best location was a more difficult one in the less rugged country.

Clear Fork River cuts through Pine Mountain in a gorge called "The Narrows," so rugged that no domestic animal had ever traversed it. It lay across the straight line joining Saxton and Knoxville. The stream, Big Creek, cuts through Cumberland Mountain at Big Creek Gap, which lies some 24 miles from Saxton and about 4 miles west of the direct route. Further, a branch line of road had been constructed through this gap (Fig. 104), and to a connection with the Southern Railway near Careyville. At the gap, the mining town of La Follette, with limestone and sandstone quarries, coal and iron mines, coke ovens, a furnace, etc., had sprung up and in three years had grown from a village of less than 500 to a population of more than 6000. Thus these two water gaps were objective points. In fact, the route through these points had often been explored, and at least two careful surveys had been made on it during the twenty years or more that the Louisville and Nashville Railroad had had under contemplation the extension of their Knoxville Division to the city for which the division was named. As there were watercourses leading from each of these points toward the other, the choice of the route joining them lay

simply in deciding which slope of the narrow valleys offered the best support for the adopted gradient. But these valleys were so tortuous and narrow that in a distance of three miles on one of them it was necessary, even when using 10-degree curves with 300-foot minimum tangents, to bridge the watercourse ten times and use three short tunnels.

It was plain, from the conformation of the country, that there would be long ascents and descents on whatever ruling grade was adopted. The chief local product of the country being bituminous coal, in great quantity and of good quality, the market for which could only be southward since the country to the north and west was tributary to the Pittsburg coal fields and that to the east to the Virginia coal fields, it was good economy to spend more money to secure light grades against south-bound trains than for trains in the opposite direction.

The writer decided on 53-foot compensated grades as the maximum, but an economical construction required the introduction of a 61-foot grade on the long descent from the Cumberland-Clinch Divide to La Follette. The road was located from Saxton to this divide on this ruling grade, with an inconsiderable amount of adverse grade two miles from Saxton, at a point where its introduction was comparatively harmless.

An adverse grade has been defined as a grade pitching in the opposite direction from the general slope of the country. Of course, it means the introduction of just so much rise and fall which could be avoided.

The line from La Follette to Knoxville had not been reconnoitered. It seemed possible to get a line from the Cumberland-Clinch Divide down to the Clinch without adverse grade; but from the Clinch to Knoxville, across the short ridges and valleys, it seemed that the road would have to "rise and fall with the country," and the writer expected at the outset that the condensed profile of this part of the line would look like the teeth of a saw. From La Follette toward Knoxville, the narrow and tortuous valley of Big Creek seemed to offer the most available route in the desired direction; but to get from the Clinch, at the mouth of Big Creek, across to Knoxville on 1-per cent grades was out of the question, unless one made up his mind to make long tunnels through nearly all the ridges and to make high crossings over the narrow valleys. The difficulties and expense were so great that this route was never contemplated seriously.

By going down Big Creek from La Follette to the Clinch, however, and then turning down the Clinch as far as the mouth of Bull Run, below Clinton, and by making three crossings of the Clinch, a route was possible, leading through Clinton, a town of 1200 people, which gave no adverse grade from La Follette to Clinton and an adverse grade of only 48 feet, vertical, between Clinton and Bull Run, at a point about four miles southwest of Clinton where it was necessary to cut across country, leaving the river, to save distance and excessive curvature.

The absence of adverse grade was considered so advantageous on this route that a careful survey was made over all the difficult portions of it, and careful estimates were made of the value of its advantage and cost as compared with the route adopted finally; but the absence of adverse grade was its sole recommendation. There were many serious objections to it. First, to follow Big Creek Valley below La Follette required bad alignment, several short tunnels and expensive construction; second, the three crossings of the river involved expensive bridging; third, the distance from La Follette to Clinton was greater than by the route adopted finally; and, fourth, it led out and away from the coal fields, and through a country from which the timber had already been stripped and from which little development could be expected.

From La Follette to Clinton the route adopted originally followed very closely the line described previously as dividing the country into dissimilar sections. The route could only be adopted at the sacrifice of introducing a considerable amount of adverse grade at four different places (Fig. 105 at *A*, *B*, *C*, and *D*). There were 28 feet, vertical, at *A*, 12 at *B*, 40 at *C*, and 132 at *D*. But the line was much cheaper than the Big Creek-Clinton line, afforded much better alignment, and, besides following the edge of the coal fields, passed through the town of Coal Creek, the center of a population of some 5000 people, where coal mining had been carried on successfully for a quarter of a century.

The location from the mouth of Bull Run to Knoxville introduced more difficult problems than any other part of the line; and the writer believes that the combination of conditions which enabled this line from the Clinch to Knoxville to be laid out, on the original 53-foot grades, without one foot of adverse grade and without a tunnel or high valley crossing, is unique and unusual in such rough country. The profile of the Southern Railway line from Clinton to Knoxville

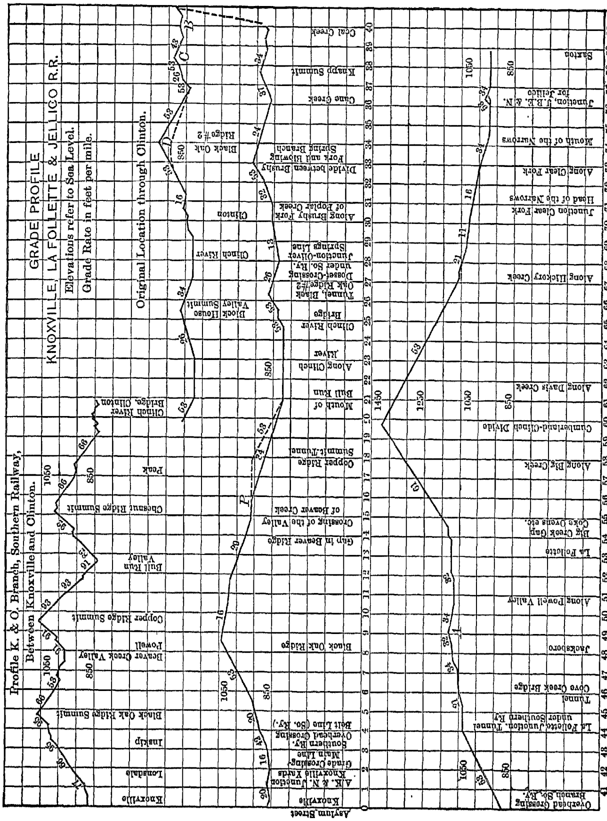

GRADE PROFILE
KNOXVILLE, LA FOLLETTE & JELLICO R.R.
Elevations refer to Sea Level.
Grade Rate in feet per mile.
Original Location through Clinton.
Profile K. & O. Branch, Southern Railway,
Between Knoxville and Clinton.

Fig. 105.

(see Fig. 105) is a fair representation of the necessary line that goes plunging across these ridges. An old locating engineer, of the Cincinnati Southern, years before, made a location survey from Harriman to Knoxville which passed through the same gap in Copper Ridge as that used by the writer. He used 66-foot uncompensated grades, and got a wonderful amount of rise and fall into his line between Copper Ridge and Knoxville, about 130 feet of it being between Copper Ridge summit and Beaver Creek.

At the crossings of the parallel valleys of Bull Run and Beaver Creek by the Southern Railway line, the latter valley is the higher by some 140 feet; and the writer decided to cut through Copper Ridge, by a tunnel if necessary, at the level of the upper valley, to save all unnecessary rise and fall. It was found on examination that the two valleys, though one was so much higher than the other, had practically the same rate of fall, some 30 feet in the 7 miles below the Southern Railway crossing, so that the point *P* (Figs. 104 and 105), in the open valley of Beaver Creek, was 140 feet above the country at the mouth of Bull Run. At the point, *P*, however, where the stream turned and ran directly toward the only available gap in Copper Ridge, the valley began to descend much more rapidly down to the level of the Clinch. It was just possible, on the original 1-per cent grade (see Plate I), to start the grade at the mouth of Bull Run and make the elevation of the upper valley by the time the summit of the ridge was reached at the gap. A cut, 68 feet deep, containing 186,000 cubic yards of clay, chert, and rock excavation, was necessary in cutting through the ridge. Supporting ground on the side of the ridge was found from the ridge summit to the point, *P*, for a level grade, so the road reached *P* without any unnecessary rise and fall. A water gap in the desired direction led through Beaver Ridge. This gap drained a portion of the open valley (Hines's) between Beaver Ridge and Black Oak Ridge into Beaver Creek, and the three parallel valleys thus made a succession of steppes which were used to support the gradient from the Clinch to the summit of Black Oak Ridge at the lowest available gap. The alignment was excellent, and the country easy from the point, *P*, to the summit of Black Oak Ridge, and from there the road descended in fairly easy country to Knoxville.

There were, in all, five well-equipped engineer parties between Jellico and Knoxville, and the chiefs of parties were cautioned to

use as light grades and curves as they reasonably could at all times.

Just here, at the risk of reiterating much that has already been written, the writer wishes to emphasize the necessity, in making such surveys as this:

(1) Of not using at any point any more difficult gradients nor any stiffer curves than the country actually requires;

(2) Of completing a condensed profile of the whole line as soon as the surveys are connected throughout;

(3) Of compensating for curvature the prevailing long grades of less rate than the maximum; and

(4) Of making a diligent study of the whole country, with a view of selecting a route with a minimum of adverse grade.

Some of the locating engineers were sent back over their work several times to see if they could not get through with lighter grades and curves, even though the grades and degree of curve used had been less than the maximum, and more than one of them made very material reductions in the grades which had been used, as well as in the degree of curve, without increasing the cost of the work materially.

When the condensed profile was made, after the lines were tied up, it was shown that there were only three points where it had been necessary to use 53-foot grades against south-bound trains, *viz.:* the ascent to the Cumberland-Clinch Divide, 8 miles in length; the ascent to Black Oak Ridge No 2, 2¾ miles in length, and the ascent to Copper Ridge summit, 3 miles in length. Up to the time of the completion of this condensed profile, none of the higher officers of the road had hoped to get any better ruling grades through this country than 1-per cent compensated. When the writer decided tentatively on the 1-per cent grades, the consulting engineer of the road said to him, "If you can make it from La Follette to Knoxville on one-foot grades you will be doing mighty well." No other road crossing these mountains anywhere in this section of country had secured anything like such a favorable gradient as this. Lines crossing these mountains, as far south as Birmingham, where the elevation of the Appalachian province is so much less, such as the Georgia Pacific line of the Southern Railway from Birmingham to Atlanta; and the Central of Georgia, Birmingham to Opelika, built in the Eighties, had used 66-foot grades.

Except the three long grades mentioned, the heaviest south-bound grade was 0.65 per cent; and the advisability of reducing these three 53-foot grades to 34-foot grades was at once suggested. What was the reduction worth and what would it cost?

The Cost of the Change.— It was plainly out of the question to reduce the ascent to the Cumberland-Clinch Divide to this gradient. It was too long, and involved construction which was too expensive. If the road was to be operated on the lower grade, it was plain that a helper engine must be used on this grade, and, therefore, the cost of maintaining a helper engine would be a legitimate charge against the change to 34-foot grades. Assuming that the traffic would be proportioned as below, and that the schedule could be arranged so that one engine crew could do the helper service, the annual cost of this service would be about as follows:

Interest on \$14,000, cost of helper engine, at 4 per cent.......	\$560
Twelve months' wages of crew, at \$312	3,744
32,544 engine-miles, at a cost of 17.3 cents per mile, for repairs, fuel, water, stores and roundhousemen....................	5,630
Cost of 32,544 engine-miles to maintenance of way and structures, at $\left(22\frac{1}{4} \text{ per cent of } \frac{\$1.08}{2}\right) = 12$ cents....................	3,905
Total annual cost of helper-engine service	\$13,839

In the foregoing estimate, the cost of engine repairs, fuel, etc., is taken from the report of the Pennsylvania Railroad Company for 1902. It is assumed that the engine does half as much damage to the track as the train, the cost per train-mile being \$1.08 and the cost to maintenance of way and structures being $22\frac{1}{4}$ per cent per train-mile. We assume four round trips of 24 miles each per day, from the head of the Narrows to the end of the siding south of the divide, half the trains not running on Sunday.

Then, if the road's capital could be acquired at 4 per cent interest, the cost * of establishing and maintaining the helper service would be \$345,975.

It was easily ascertained that by making a 700-foot tunnel at Black Oak Ridge No. 2 the grade there could be reduced to 34 feet without lengthening the line and without any more expensive construction, except the cost of the 700-foot tunnel; and, further, the tunnel would save 50 feet, vertical, of the adverse grade.

* Capitalized Cost.— W. G. R.

Plate I is a map and profile of the old and new line at Copper Ridge. By dropping the grade line about 50 feet at the summit and making a 2170-foot tunnel, and by taking advantage of the sharp fall in Beaver Creek Valley from the point, *P*, toward the gap, the 34-foot grade could be used even here without lengthening the line and without increasing the cost, except by a portion of the cost of the construction of the tunnel. In fact, the lighter grade threw the line off from the upper cliffs of the ridge in certain places down on to the talus slope on smoother ground, with the result that a very much better line, both in alignment and first cost (except for the tunnel), was obtained. In the revision surveys here a maximum curvature of 6 degrees was substituted for 10 degrees. This change had the effect of placing the tunnel of the summit of the ridge on the grade up to Beaver Creek Valley, and there was elevation enough to spare to permit of dropping the grade to 23 feet per mile through the tunnel, thus compensating for wet rails by more than 0.2 per cent. Thus the cost of the change at these two points was not in excess of the cost of the other line by anything like the full cost of the tunnels. The construction contracts which had been made would warrant the belief that the tunnels could be constructed at a much lower figure, but, inasmuch as these tunnels had to be constructed in part through very treacherous clays, it will be supposed that they would cost $90 per linear foot. Not considering the 50 feet of adverse grade, saved at Black Oak Ridge No. 2, the additional cost of the two tunnels would be about as follows:

700-foot tunnel at Black Oak Ridge No. 2, at $90	$63,000
2170-foot tunnel at Copper Ridge, at $90	195,300
Total	$258,300

Less cost of summit cut at Copper Ridge :

93,000 cubic yards, earth excavation, at 20 cents.	$18,600	
49,000 cubic yards, chert excavation, at 28 cents.	13,720	
44,000 cubic yards, rock excavation, at 70 cents.	30,800	
		63,120
Additional cost of tunnels		$195,180

The approaches to the tunnel at Black Oak Ridge No. 2 were very nearly as costly as the original summit cut. There was another expense which constituted a legitimate charge against the construction of the tunnels. Up to the time of the contemplated change, the longest tunnel on the road was in the mountain district, in good

material, and was less than 900 feet long. It was certain that the construction of these tunnels would take much longer than the remainder of the road; therefore, the interest on the money invested in construction, including the cost of the valuable property purchased in Knoxville for terminals, from the time that the other work could be completed until the tunnels could be completed, constituted a proper charge against the proposed change. Taking the amount expended in other construction, etc., as $3,500,000, with interest at 4 per cent, and supposing that the tunnels delayed the opening of the road for traffic one year; then the total cost of changing to the lighter grade for south-bound trains would be as follows:

Establishing helper-engine service on the Cumberland-Clinch Divide	$345,975
Additional construction cost of two tunnels	195,180
Interest on $3,500,000 for one year at 4 per cent, on account of delay	140,000
Total cost of change to lower grade	$681,155

The Value of the Change.— The value of such changes is difficult to estimate with accuracy, even on an operated road on which the traffic is known. It was reasonably certain that the road would not be in operation many years, if operated on 53-foot grades, before as many as ten trains per day each way would be required to do its business. Considering the traffic the road would have, probably six of these trains south-bound would be fully loaded. Four fully loaded trains per day, on a 34-foot ruling grade, could just about do the work of six fully loaded trains per day, on 53-foot grades, using engines and cars of the same class. Since the north-bound traffic would include a large quota of empty coal cars, and since the same engine that pulled, say, twenty-three loaded 40-ton cars southward against the 34-foot grades could pull forty-nine empties back against the 53-foot grades as far as La Follette and forty-four empties back, even against the 61-foot grade, it was probable that eight trains per day each way on the lesser grade would do the work of ten trains per day each way on the higher grade. Operating expenses vary directly as the train-mileage, and the cost per train-mile on the Louisville and Nashville for the year ending June 30th, 1902, is given in "Statistics of Railways" by the Interstate Commerce Commission as $1.08. However, it is a fact that the operation of such heavy trains as these costs more than the general average on a large system. The cost per train-mile on the Duluth and

Iron Range and the Duluth, Mesaba and Northern, two roads engaged almost exclusively in traffic similar to that which these omitted trains would represent, is given, by the same authority for the same year, as \$1.94 and \$2.61, respectively. Probably it would be safe to estimate the train-miles saved at \$1.50, but the more conservative figure will be taken. Suppose that half these trains run on Sunday.

Then the annual saving from Saxton to Knoxville would be \$1.08 x 4 x 79 x 339 = \$116,000, nearly, and the value of this annual saving in operation, with interest at 4 per cent, would be	\$2,900,000*
The cost of the change, as above	681,155
The amount gained by the change	\$2,218,845

However, since helper-engine service could be established and maintained also at Black Oak and Copper Ridges, at a probable cost of \$227,000 at each place, the engine mileage at either point not being more than half of that at the Cumberland-Clinch Divide, the utmost amount it would have been economical to spend on the change at these two points was about \$454,000. Thus it was more economical to build the tunnels by the amount of \$454,000 less \$195,180 + \$140,000, or \$118,820. As soon as the President of the Louisville and Nashville Railroad understood the matter fully he authorized the change, without hesitation.

When the order was made to reduce the south-bound grades to 34 feet, there were some long minor grades on which the curvature had not been compensated, so that the total resistance was above that of the new ruling grade. As the construction had barely begun on most of the line, the corrections were inexpensive; but, if the road had already been in operation, the failure to compensate the prevailing minor grades would probably have resulted in the adoption of a higher ruling grade than that which was applicable to the country. Even if the heaviest grades had not been reduced at the time, with the probable heavy traffic in prospect, it was almost certain that sooner or later the heaviest grades would have been reduced or operated by helper engines, so that it is clear that the heavier minor grades should have been compensated at the outset.

It was also now contemplated to reduce the south-bound grades back on the operated road, between Saxton and Corbin, and also on the Atlanta, Knoxville and Northern for some distance below Knox-

* Criticism of this estimate appears in the discussion of the paper.—W. G. R.

ville, to the same rate. Thus the plan became a part of a more comprehensive scheme.

Now, it is true that, under ordinary conditions, if the road were laid out contemplating the use of a helper at any point, this adopted ratio of 1 per cent and 0.65 per cent for the helper grade to the ordinary is uneconomical; but, if the helper engine is to be of the same class as the regular engine, the helper grade, ordinarily, could be as heavy as 1.4 per cent, if the grade for the regular engine was 0.65 per cent. But there were very good reasons why this 1-per cent grade against south-bound trains was not altered:

(1) The contract for the construction of the road through the mountain district had been let for some months, and the work was well under way before this change to 34-foot grades was contemplated.

(2) The 1.4-per cent grade would not have shortened the line at all, and the valley into which that grade would necessarily have descended was so narrow and rugged that there would have been little saving over the 1-per cent grade.

(3) On account of the peculiar conditions under which the road would probably be operated, it was in no wise certain that the 1-per cent grade would be used as a helper grade. But even if it were, and the grade revision was carried back or forward on the old road far enough to make up a complete freight division, there would be many a train which would not require the service of the helper on a 1-per cent grade, and yet certainly would on a 1.4-per cent grade.

The writer does not pretend that these adopted grades of 53 feet and 34 feet south-bound, and 53 feet and 61 feet north-bound, were studied out and adjusted accurately to the needs of the future traffic. The probable future traffic was considered, but the grades adopted were simply the best that the country afforded at a reasonable expenditure of from $40,000 to $60,000 per mile, below sub-grade, each of them being fixed by long, continuous ascents — to alter materially any one of which for the better could be done only at an expenditure not warranted by the anticipated traffic.

On the supposition that the plan of reducing south-bound grades on the old road was not carried out, the scheme of operation, as affected by these grades, without using a helper engine, could be outlined roughly as follows:

It was certain at the outset that a spur line would branch off at the south end of the Narrows to the excellent, but undeveloped, coal

fields of the Clear Fork and Laurel Fork Valleys. It was also certain that a spur line would branch off in the neighborhood of Clinton to the coal fields in the vicinity of Oliver Springs. Thus, in operation, freight trains out of Knoxville would set off empties along the route until they were lightened sufficiently to pull up the 61-foot grade north of La Follette. Going south, trains would leave the head of the Narrows with only such loads as they could pull on the 53-foot grades, and would pick up enough loads at La Follette and other points on the route to load them fully into Knoxville.

The writer has been so impressed with the number of instances he has met in his practice in which engineers have lost sight of the important fourth principle, mentioned on page 341, that a special instance, illustrating how some expensive and unnecessary rise and fall was avoided, will be cited.

The survey for this road was commenced, under other engineers, at La Follette, at the station of the Tennessee Northern, and proceeded northward. The idea in mind was to parallel the Tennessee Northern through the town (Fig. 106), and to use the station, already built, for both roads. The same parties controlled the Tennessee Northern, all industries, and most of the land near La Follette, and it was considered by them of very great importance to their plan of development that, through the town, the old road should be paralleled by the new. The 6½-mile, 61-foot grade, from the Cumberland-Clinch divide did not "touch bottom" until just before the station was reached. The profile shows "the hole" in which the station would have been if the original location had been retained. It happened that it was some months after the original line from La Follette northward was run before the writer sent an engineer to La Follette to begin the survey for the extension of the line toward Knoxville, and the idea that the location of the road through the town was fixed as above had pretty well crystallized in the minds of all concerned. This engineer's instructions were to start at the summit south of La Follette (at Station 410, which was an objective point) with the grade elevation of the Tennessee Northern in the summit, and find supporting ground back through the town for a level grade, extending it back into the gap to an intersection with the long 61-foot grade. The map and profile show the line that was secured. It was about as cheap to construct as the other, gave less curvature, and was some 700 feet shorter. It placed the station about 300 yards

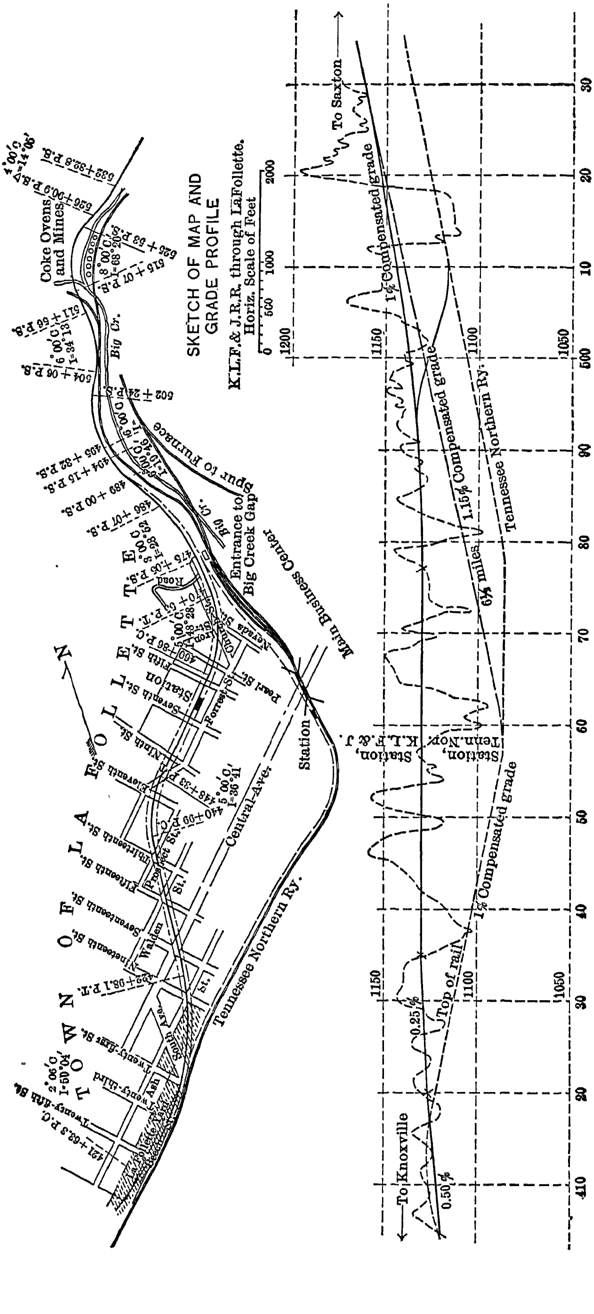

SKETCH OF MAP AND
GRADE PROFILE
K.L.F.& J.R.R. through LaFollette.
Horiz. Scale of Feet
TOWN OF LA FOLLETTE
Coke Ovens and Mines
Big Cr.
Spur to Furnace
Entrance to Big Creek Gap
Main Business Center
Station
Central Ave.
Tennessee Northern Ry.
To Saxton
To Knoxville
1% Compensated grade
1.15% Compensated grade
Tennessee Northern Ry.
6¼ miles
Station, K.L.F.& J.
Station, Tenn. Nor.
1% Compensated grade
Top of rail
0.25%
0.50%

Fig. 106.

further from the center of the town than the other station would have been, but good connection with the track leading to all the La Follette industries could be had at the summit mentioned and at the point, *F*. This point was just south of the intersection of all tracks on the Tennessee Northern leading to all the coke ovens and coal mines, and was just north of all tracks leading to the three crushers, brick-yards and furnace; and the only land available for yards for the new road, in the vicinity, was at and near this summit at Station 410.

There was vigorous opposition to the new location through the town, however, but the common-sense view of the matter prevailed in the end, and the road was built, as it should have been, on the upper grade line.

The comparative advantage in operation of this upper line was so palpable that it was never attempted to calculate how much more economical it was than the other line. To have put the station for this important town in such a place as was contemplated, with 43 feet, vertical, of unnecessary maximum grade immediately on each side of it, would have been bad engineering, even if the traffic from this point alone was to be considered; but to put a station on a through line in such a place, at which all heavy trains would probably have to stop, when it could be avoided at any reasonable outlay, would have been the height of folly.

After all the contracts for the construction of the main line and the Clear Fork Branch were let, it was found that it required very expensive construction to connect the Oliver Springs line, either at Lee's Ford or just on the north side of the Clinch, 2 miles below Clinton, which were regarded as the only available points. The proposed routes united near Dosset. To reach Dosset from Lee's Ford required 3 miles of road, a bridge over the Clinch, and a tunnel through Black Oak Ridge No. 2. To reach Dosset from the second point required 5 miles of very heavy work and a tunnel through the same ridge. Either plan of building the branch line, then, would necessitate tunneling this ridge twice, once for the main line north of Clinton and once for the branch line southwest of Clinton. Since it was a fixed fact that the branch line would be constructed, it was suggested that it might be better to turn the main line southwest at a point 3 miles south of Coal Creek, take it through Dosset and make the point of junction for the branch line at Dosset. This plan would save the construction of one tunnel, and either one bridge over

the Clinch and the construction and operation of 3 miles of road or the construction and operation of 5 miles of road. But it would miss the town of Clinton. Examination showed that, when the construction of both the main line and the branch line was considered as a whole, the proposed change was advantageous in point of alignment, distance, and economy. The gradients of the main line were not benefited materially by the change, but those of the branch line were benefited very much. To tunnel the ridge on the branch line, with the gradients adopted for it, would have required 2500 feet of tunnel, but the gradients now decided upon for the main line required 3520 feet of tunnel. Thus, by saving the 700-foot tunnel and the 2500-foot tunnel, and making the 3520-foot tunnel, there was 320 feet more of tunnel to construct, but the cost of the expensive approaches to one of the tunnels was saved.

The town of Clinton was already well provided with railway facilities, and it had not the population nor any industry to give it claim for consideration against such advantages. The last census showed that it was decreasing in population. Therefore the line was changed to pass through Dosset; and the further advantage was secured that, against south-bound trains, the two principal branch lines have the same limiting gradients as the main line. Thus the road is laid out somewhat on the same principle as that by which a stream departs from its direct course to meet its principal tributaries.

The road, as located finally, is 78.8 miles in length, from Saxton to Asylum Street in Knoxville, making the length of road exceed the straight-line distance 55 per cent instead of 34 per cent, as by the Knoxville and Ohio Branch of the Southern between the same points.

The roughest country encountered was from the head of the Narrows to the Cumberland-Clinch Divide, and here 10-degree curves were used. Quite expensive construction was necessary on the south side of this divide as far as La Follette, and here a maximum of 8-degree curves was used. Rough country was also encountered in the 6 miles north of Coal Creek, and on the ascent through Copper Ridge. The sharpest curves used at the last two points were 6 degrees; the remainder of the road was located on light curves, so that the points where curvature would reduce high speeds materially were bunched. From Saxton to La Follette there are ninety-two curves, the total angle turned being 3717 degrees, or 145 degrees of curvature per mile. From

La Follette to Knoxville there are one hundred and nineteen curves, with a total central angle of 3692 degrees, or 69 degrees of curvature per mile. The minimum tangent was 300 feet, and all curves above 2 degrees were spiraled. The Holbrook spiral, with three different rates of spiraling, was used. For curves under 5 degrees, a spiral increasing 1 degree in 60 feet was used (called a 60-foot spiral). For curves above 5 degrees and under 7 degrees, a 30-foot spiral was used, and for curves of from 7 to 10 degrees, a 24-foot spiral was used. It will be noticed that the rate of spiraling is changed sharply in passing from curves of about 4 degrees to those of lesser radius. The reason for this was that curves of 4 degrees and less, with 60-foot spirals, were intended to be used in open country, and the curves of higher degree, with the 30-foot spirals or less, were intended to be used only in country where it was necessary to use curvature of such high degree as would necessarily limit the speed of fast trains. The curves were located originally without spirals, but the resident engineers put in the spirals just before staking out the work, so that the road was constructed on the spiraled alignment. It will be noticed that these spirals would all fit in, usually with some distance to spare, on the 300-foot tangents.

The grade breaks were rounded off by vertical parabolic curves, changing the rate of grade 0.2 foot per 100-foot station at summits, and 0.1 foot per 100-foot station in sags.

On the final location adopted, there were seven tunnels, in the 79 miles of road, aggregating nearly 10,000 feet in length. One of these tunnels in the mountain district was located partly on a 10-degree curve, so that the spiral approach curve, with its varying curvature and rail superelevation, came within the tunnel. The rule used for increasing the tunnel section, so as to give at every point practically the same clearance as on tangents, for an 80-foot Pullman or dining car, was:

"Widen the tangent section $\frac{13}{16}$ inch per degree, both on the inside and on the outside of the curve. In addition, widen the section on the inside of the curve $2\frac{11}{16}$ inches per each inch of superelevation."

This particular tunnel was in hard sandstone not requiring lining. The tangent section was rectangular from subgrade to 17 feet above (16 × 17), with curves of 5-foot radius in the upper corners. The rule gives a slight excess of clearance on the outside of the curve, which, to some extent, allows for the compression and swing on the car springs.

At the time of writing this paper (December, 1903), practically all the grading, except that in the Knoxville yards, is completed. Several of the tunnels are completed, but the 3520-foot tunnel at Dosset cannot be completed, probably, before some time in the summer of 1904. The main line is being built with permanent structures, no timber bridges or bridge supports being used, except four wooden trestles which are to be filled in, eventually, with steam shovel and train.

Of openings on the main line, there are eleven concrete and stone masonry arches of from 12 to 26 feet span. There are thirty steel bridges, on masonry piers and abutments, and two viaducts of 1420 feet, total length. These steel bridges consist of three through spans, one of 150 feet and two of 200 feet, and sixty-seven plate girders of the following kinds, writing their lengths to the nearest 5 feet: One 40-foot through, one 45-foot through, one 80-foot through, and one 45-foot double-track deck; and single-track deck girders of the following lengths and number: Two 14-foot, six 30-foot, six 40-foot, eleven 45-foot, one 50-foot, nine 60-foot, twenty-one 70-foot, one 90-foot, and one 120-foot. In these structures there are 43,529 cubic yards of first- and second-class bridge and arch masonry. In addition, there are 37,248 cubic yards of culvert masonry.

The total cost of construction of the main line ready for operation, exclusive of rolling stock and equipment, is now estimated to be $5,450,000, or a little in excess of $69,000 per mile. The cost of the Oliver Springs Branch is estimated to be $300,000, and of the Clear Fork Branch $93,000.

As will be inferred from the foregoing discussion, in the lay-out of the road, far more weight was given to gradient and the securing to traffic than to curvature and distance. If economy in operation is in any wise proportional to the smoothness of the grades, it is an economically located road, considering the country. In seeking a measure of grade smoothness for such a purpose, the smoothness of a gradient should be taken to vary inversely as the total number of feet, vertical, ascended and descended on maximum, or at least on expensive, grades; but, taking the smoothness to vary inversely as the total number of feet ascended and descended, some interesting comparisons may be shown.

From the crossing of the Clinch, at Clinton, to Knoxville, on the Knoxville and Ohio Branch of the Southern, the total rise is 641 feet

and the total fall 601 feet, or a total average rise and fall per mile of 59.2 feet. From the crossing of the Clinch, on this line, to Knoxville, there are 290 feet of rise and 264 feet of fall, making a total average rise and fall per mile of 21.5 feet. Measured as above, the smoothness of this new line exceeds the smoothness of the old line, in the same country, by 173 per cent.

In this respect, the smoothness of this road compares favorably with the smoothness of some prairie roads. The average total rise and fall per mile from Saxton to Knoxville is 26.2 feet. The average total rise and fall per mile of one of the principal roads from Kansas City to Chicago, for the first 100 miles out of Kansas City, across the Missouri prairies, is 37.2 feet per mile. Thus, measuring grade smoothness by this standard, the smoothness of this mountain road, crossing the direction of the prevailing ridges and ranges, exceeds the smoothness of this prairie road by 42 per cent.

EMILE LOW, M. AM. SOC. C. E. (by letter). — (Mr. Low's discussion consisted of an account of the location of the Clinch Valley Division of the Norfolk and Western Railroad, and while interesting is not reproduced in full. The closing paragraphs follow.)

Before closing, the writer would like to add a few remarks in regard to the proper method of conducting railroad locations. It is the practice to cut up a proposed line of railroad into sections and allot one of these to each survey party. This is good as far as it goes, but the trouble is that each party is generally allowed to follow its own bent, in fact, to roam at its own sweet will, instead of filling in a part of a harmonious whole. Bad locations also result from improper organization, an insufficient number of members in the parties, delegating to the chiefs of parties such work as sitting up all night in a tent plotting the day's work, when such duties ought to be performed by draftsmen, especially provided for in suitable quarters, as well as in daylight.

With proper methods, surveys can be kept plotted up to date, and the locating engineer can thus have a broad view of the ground he is covering, and also an intelligent idea of where to run additional lines, when needed to cover doubtful points. In addition, copies of all notes, including transit, level and topographical notes, should be sent (or mailed) to headquarters, at frequent intervals, to be worked up at once.

This enables the chief engineer to see what is being done in the

field, and also keeps him in close touch with all his assistants. Thus he can give such orders as to changes and improvements in the whole line as will result in producing a perfect design.

William P. Watson, M. Am. Soc. C. E. (by letter). — This paper has been read with much pleasure. The author is correct in the statement:

"The economic questions which determined that the whole project of construction was advisable may be of more importance than the most intricate and learned calculation upon the strength or efficiency of special structural parts."

By the former, the economic success or failure of the enterprise as a whole is determined, while the failure of the latter affects, generally, only one part, and often a very small part, of the whole enterprise, and can be remedied easily by a more skilful and complete structure. For this reason, a skilful and scientific location of any given line of road is very rarely appreciated. As formerly stated, the work of the locating engineer may determine the success or failure of any given enterprise.

Of course, the determination to construct a line between two termini is the province of the executive branch of the road, but, even for this purpose, who can be a better adviser than the skilled engineer? After this has been determined, there come the minor economic questions of the selection of the route, wherein must be considered: First, the best route for traffic and the probable volume thereof; and secondly, the various questions as to the proper gradients, distance, rise and fall, and curvature, their degree of importance being in the order named. The first affects the revenue of the road, and the last four affect the yearly operating expenses, or the profits of the enterprise. They are as legitimate and proper subjects of consideration by the locating engineer as is the first cost of the construction; for they are taken care of by the annual operating expenses and the latter by the annual interest, or fixed charges; and yet what great sums are spent on railway construction without even considering any of these questions except, probably, gradients. The writer has known chief engineers, who, after the ruling gradient had been decided upon (probably by the executive department, or management, from what it wanted and not from a scientific study of the subject), appeared to attach no importance to the other questions, indeed, had no thought or opinion upon them; and, when a comparison between any two lines was made,

almost invariably took the line that showed the cheaper construction, no matter if obtained by almost any excess of distance, rise and fall, or curvature. And yet such men are entrusted with works of great magnitude, amounting to thousands and millions of dollars. It is only the abounding prosperity of the nation, and not the skill of the engineer, which, when such methods are allowed, makes an enterprise a success instead of a failure. It is therefore refreshing to see a location in which such questions have been considered.

The writer has given the paper only a hasty examination, but notes the following points:

Adverse Grade. — It would seem that the author has given an undue and disproportionate weight to the subject of adverse grades, and has fallen into the common error of adding up all the rises and falls, no matter how small, for any two compared lines, and giving the preference to the one having the greater aggregate total. This may be very fallacious, as that showing the lesser may have all its rises and falls in two or three long stretches of 10,000 feet or more, and be very objectionable, while the other may have an undulating grade with numerous short rises and falls, of less than, say, 30 or 40 feet, so arranged that traffic can be handled as cheaply as on a level grade, upon the theory of "momentum or velocity grades" which is illustrated as follows:

Theory of Momentum or Velocity Grades. — A constant power (the locomotive) is applied to overcome the train resistance, then the un-

TABLE NO. 2.

Mile.	Elevation (or lift), in feet.	Difference in elevation of sags and summits, to be added or subtracted.	Equivalent lift, in feet.	Equivalent speed, in miles per hour.
100......	0 (It is assumed that at Mile 100 the train has a speed of 30 miles per hour)			30
102.2....	95.8	+ 32*	127.8	60
104.4....	127.8 (lift due to 60-mile speed)	−(95.8+24)	8.0	15
107.2....	8.0 (lift due to 15-mile speed)	+ 24.0+64.8	96.8	52
110......	96.8 (lift due to 52-mile speed)	−(64.8+20.0)	12.0	18
114......	12.0 (lift due to 18-mile speed)	+ 20.0+62.0	94.0	51+
115.1....	94.0 (lift due to 51-mile speed)	−(62.0)	32.0	30

* Original potential lift, due to a speed of 30 miles per hour.

dulations, or various rises and falls, are overcome by the momentum, or stored energy, which is increased, or stored up, on the descents and given off on the ascents, as illustrated in Fig. 107. This is what engine men mean by the expression "taking a run at a hill."

Fig. 107 represents the profile of an imaginary line whereon a locomotive is supposed to be able to haul a train on a level grade at 30 miles per hour and to exert the same tension upon the draw-bars up and down hill, the alignment being arranged so as to allow of very fast speeds. The calculation of the different speeds is illustrated in Table No. 2.

A train in motion at 30 miles per hour has a potential lift of 32 feet, vertically.

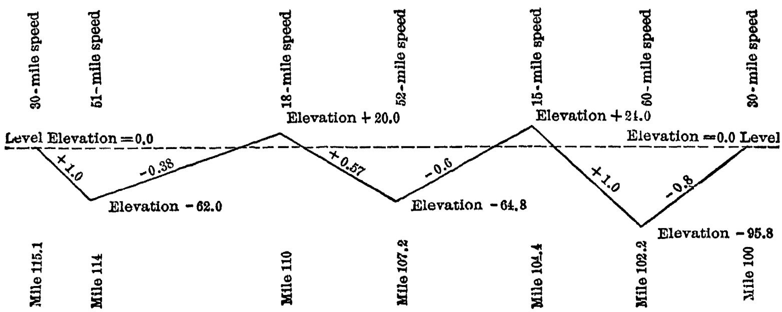


Fig. 107.

Thus the table shows that at Mile 115.1 the speed is 30 miles per hour, or the original starting velocity.

Is it not evident that a road constructed on such a profile can be worked as cheaply as an equivalent level road (except for the practically unmeasurable wear and tear on track and rolling stock due to varying speeds), and with actually no more application of power, provided the velocities can be maintained safely?

The writer would not advise carrying this to the extent suggested by Wellington, that is, using grades greater than the maximum, in these sags and rises, for, although this is correct, theoretically, it pre-supposes always an unobstructed track. While this may generally be so, it may not always. Suppose the grades on each side of the sag at Mile 102.2 were beyond the maximum. Is it not apparent that any obstruction necessitating a stop there would stall the train and impede, or tie up, the traffic for the entire division, invalidating all its fine-spun theories and elaborate calculations? A slippery rail

near the summit might have the same effect, for, though this might not interfere with the potential lift, it would interfere with the constant force, the locomotive, because, with freights especially, the ability to start a given load up any grade limits the amount of that load, and, if it were not for the elasticity in the springs of the couplers, it is doubtful whether an engine could start a load which it could readily pull.

This would indicate that these sags could be made 80 or 90 feet, but the line must be located for its weakest member, which would be a freight of 40 or 50 cars, with speeds of from 15 to 30, or 25 to 40, miles per hour.

With speeds of from 15 to 30 miles per hour the safe sag would be

$$(3.0^2 \times 3.55) - (1.5^2 \times 3.55) = 24 \text{ feet.}$$

With speeds of from 25 to 40 miles per hour, the safe sag would be

$$(4.0^2 \times 3.55) - (2.5^2 \times 3.55) = 35 \text{ feet.}$$

Therefore, a line located with an undulating grade, containing sags not exceeding 30 feet, or on special occasions 40 feet, would be within safe limits, provided the ruling grade were not exceeded.

The foregoing calculations are dependent on the ability to maintain fast speeds. Therefore, anything which would interfere with this should be avoided. A sharp curve at the bottom of a sag, say at Mile 102.2 in Fig. 107, would not be permissible. Such a curve half way down would not be as objectionable, or could be introduced at a summit without harm, if properly compensated.

Distance. — The author has hardly given due weight to the question of distance, and the writer is not sure that the advantages attained are sufficient to compensate for the lengthening of the line about 11 miles more than that of the Southern. The operation of an increased distance of this extent will probably cost an additional 50 cents per train-mile. The cost for 10 trains daily each way, at \$1.08 per train-mile (the cost on the Louisville and Nashville System), is calculated as follows:

50 × 365 × \$1.08 × 2 × 10 trains = \$4042 per year added to general operating expenses for one train-mile, and, for 11 miles, this makes \$44,462, which, capitalized at 4 per cent per year, gives \$1,111,550.

Thus it would be justifiable to expend on first construction more than \$1,000,000 to save this distance.

Now, from an examination of Fig. 104, it looks as if this excess dis-

tance was lost between Knoxville and La Follette, and it also appears that a 1-per cent line could be obtained. Suppose such a line to have been located, following, in the main, the Southern from Knoxville to the Clinch, then, which seems to be the natural route, up the Clinch to Big Creek and up latter to La Follette. It is generally cheaper and better to keep the railroad line as near the natural drainage ways as practicable. This would also have had the advantages of opening a new and unoccupied territory. The selection of the line through La Follette and from there to Jellico seems to have been eminently wise and correct.

This supposed line between Knoxville and the Clinch would have about the same rises and falls as the Southern, the extreme elevation of any point being about the same as that of the Knoxville, La Follette and Jellico Railroad between the same points. But the former has the additional rise and fall, out of and into the valleys of Beaver and Bull Run Creeks, which amount to about 125 feet for the former and 225 feet for the latter, or a total of about 350 feet. Now, in continuous stretches of 100 feet and more, such rises and falls add to the yearly operating expenses \$1.85 per foot of rise and fall per train-mile, or, for this line, with the assumption of 10 trains per day, each way, and \$1.08 per train-mile, this would be

$$\$1.85 \times 10 \times 2 \times 1.08 = \$39.96,$$

which, capitalized at 4 per cent per year = \$999. That is, it would be justifiable to spend about \$1000 per foot to eliminate the rises and falls. The comparison, with the increase in yearly operating expenses, for the two items of distance and rise and fall, capitalized, is as follows:

THE PRESENT KNOXVILLE, LA FOLLETTE AND JELLICO RAILROAD LOCATION.

To 10* miles distance (increased) at \$100,000 per mile	\$1,000,000
First cost of excess 10 miles, say \$60,000	600,000
Total excess of present location	\$1,600,000

SUPPOSED LOCATION.

To 350 feet of rise and fall at \$1000	350,000
Total in favor of supposed location	\$1,250,000

This is upon a 1-per cent (or 53 feet per mile) ruling gradient.

But the present location is adapted for a ruling gradient of 35 feet

* Only 10 miles' increase is charged, as 1 mile may be lost in developing the supposed line to a 1-per cent grade.

per mile on all south-bound traffic, and the cost of putting this supposed line upon this basis should be deducted. Now, it seems highly probable that by constructing heavy tunnels, say two, 4000 feet long, through the summits of Copper and Chestnut Ridges, this could be accomplished. It would look as if it would be better to have a helper for the Bull Run Valley, the grade for which could be 1.55 per cent, or 82 feet per mile, two engines hauling upon this what one would haul on a 0.65-per cent grade. One engine would be sufficient, as the distance would be only 4 miles, and only south-bound trains would have to be helped. Again, probably 5 miles of extra line would have to be built for the Oliver Springs Branch, and would probably cost $30,000 per mile. There would also be two larger tunnels. The helper engine and the 1.55-per cent grade would probably bring the question of rise and fall under the rule of momentum grades, and eliminate the question from the comparison entirely. The mile of distance allowed for development would be reduced probably as much as ½ mile. The statement would then compare about as follows:

To excess cost of present location (as before)			$1,250,000
For reducing the proposed 1-per cent line to a 0.65-per cent line for south-bound business:			
2 tunnels (8000 feet) at $100		$800,000	
1 helper service (the author's cost is assumed for this, though it is thought to be high)		350,000	
Branch to Oliver Springs, 5 miles, at	$30,000	150,000	
		$1,300,000	
But from this is to be deducted the following:			
350 feet of rise and fall saved, at $1000	$350,000		
½ mile of distance, including cost of construction	80,000		
		430,000	
			870,000
Balance in favor of the proposed line			$380,000

If such a change could have been made, on the foregoing basis, it should have been done, as this is bound to be a link in the main line, and subject to severe competition. There is also the probability of the traffic increasing, thus making the comparison continually more favorable than that given.

Of course, the foregoing is merely a supposititious case, and might be wholly impractical of realization in the field, but, at least, it shows the danger of ignoring such an important economic question as 11 miles of increased distance.

TABLE No. 3. — ESTIMATED PROBABLE COST OF DOUBLING THE ENGINE TONNAGE TO HANDLE THE SAME TRAFFIC, UPON 1 MILE OF RAILROAD, DUE SOLELY TO AN INCREASE IN THE MAXIMUM OR RULING GRADIENT.

Subdivisions.	Percentage.		Added Cost.	
		Affected.	Details.	Total.
Maintenance of Way and Structures.				
Repairs of roadway	0.11732	80	0.09386	
Renewals of rails	0.02581	80	0.02065	
Renewals of ties	0.04154	80	0.03323	
Repairs to bridges and culverts	0.02000	80	0.01600	
Repairs and renewals of fences, road crossings, signs and cattle guards	0.00757	....	....	
Repairs and renewals of buildings and fixtures	0.01582	....	....	
Repairs and renewals of docks and wharves	0.00005	....	....	
Repairs and renewals of telegraph	0.00261	....	....	
Stationery and printing	0.00011	....	....	
Other expenses	0.00092	....	....	
Totals	0.23175	....	....	0.16374
Maintenance of Equipment.				
Superintendence	0.00768	....	....	
Repairs and renewals of locomotives	0.07372	90	0.06935	
Repairs and renewals of passenger cars	0.02318	05	0.00116	
Repairs and renewals of freight cars	0.05718	10	0.00572	
Repairs and renewals of work cars	0.00248	....	....	
Repairs and renewals of shop machinery and tools	0.01040	....	....	
Stationery and printing	0.00036	....	....	
Other expenses	0.00396	....	....	
Totals	0.17896	....	....	0.07623
Conducting Transportation.				
Superintendence	0.00700	....	....	
Engine and round-house men	0.09375	80	0.07500	
Fuel for locomotives	0.09337	75	0.07003	
Water supply for locomotives	0.00873	70	0.00611	
Oil, tallow and waste for locomotives	0.00429	70	0.00300	
Other supplies	0.00125	70	0.00087	
Train service	0.06545	80	0.05236	
Train supplies and expenses	0.01609	80	0.01287	
Switchmen, flagmen and watchmen	0.03070	50	0.01535	
Telegraph expenses	0.02341	....	....	
Station service	0.06902	....	....	
Station supplies	0.00347	....	....	
Car mileage balance	0.04516	....	....	
Loss and damage	0.01250	....	....	
Injuries to persons	0.00743	....	....	
Advertising	0.00378	....	....	
Outside agencies	0.02840	....	....	
Commissions	0.00048	....	....	
Rents of buildings and other property	0.00126	....	....	
Stationery and printing	0.00456	....	....	
Other expenses	0.04010	....	....	
Totals	0.56020	....	....	0.23559

TABLE No. 3.—*Continued.*

Subdivisions.	Percentage.		Added Cost.	
		Affected.	Details.	Total.
General Expenses.				
Salaries of general officers, insurance, law, etc.	0.02909	....	....	....
Estimating the extra engine to cost $12,500, and capitalizing at 4% per annum, the interest charges would be $500; and estimating the daily engine run to be 110 miles, or 40,000 miles per annum, the cost per mile is	....	....	....	0.01250
Total	....	....	....	0.48806

Ruling Gradient.—In the author's treatment of this point he is slightly in error. In the first place, it is improper to assume that trains are not fully loaded, for it is the duty of the management to see that the power is used up to its full safe capacity, thus obtaining the greatest economy. If the grades or traffic in one direction are different from those of the other, as they are, almost always, this must be made up by the size or number of trains.

Secondly, while operating expenses may vary directly as the train-mileage, they do not vary as the number of trains. This is shown in Table No. 3.

Thirdly, it seems to the writer that $2,900,000, the result of the author's calculation for the saving by the change in the ruling gradient, is fully one-half too large, and that the method shown in Table No. 3, which is practically Wellington's method, is the better. The writer has taken the annual operating sheet of the Missouri Pacific Railway for 1902, which will serve as a standard, and has reduced the various items to percentages, the gross total being unity.

The value or percentage in Table No. 3 (0.48806) is for one train one way, but if a change is made in the maximum, or ruling, gradient, it affects the load on the entire division, which, for convenience, may be called 100 miles long.

Therefore, to double the engine-tonnage to haul the same traffic, due solely to a change in the ruling gradient, on a division 100 miles long, will cost $48.806 per 100 train-miles per day, or $48.806 × 365 = $17,894.20 per annum; or, as the train-mile on the Louisville and Nashville costs $1.08, this will be $17,894.20 × 1.08 = $19,325.70 for increase of 1 engine-mile, or 100 per cent per year per daily train one way only.

Now, an engine will pull 73 per cent as much on a 1-per cent grade as upon a 0.65-per cent grade, or, to haul as much, will increase its mileage $\frac{1.00 - 0.73}{0.73} = 0.369$ per cent. But an increase of 1 engine-mile, or 100 per cent per year per daily train for a 100-mile division, is \$19,325.70, and for a 79-mile division and 10 trains daily, one way only, this change will be worth \$19,325.70 $\times$ 0.369 $\times$ 0.79 $\times$ 10 = \$55,511 saving in the operating expenses, which, capitalized at 4 per cent per annum, gives a capitalized saving of \$1,387,775 by changing the ruling gradient from 1 per cent to 0.65 per cent. But even this saving would fully warrant the change, which, therefore, was a wise and proper one.

It is manifest from an examination of Table No. 3, showing the operating expenses of the Missouri Pacific Railway, that there are many items therein which are not affected by an increased train service, as, for instance, general expenses, superintendence, etc., etc.

Vertical Curves. — For a link in a main line, when fast speeds are desired and expected, a gradation of 0.05 foot per station (100 feet) in sags and 0.10 foot at summits makes a better and more easy transition than those mentioned by the author. Some recommend even a flatter curvature, but, with the present general use of springs in couplers, 0.05 and 0.10 foot are sufficient.

Transition Spirals. — A spiral increasing 1 degree in 60 feet is too short for a line of this character, as it is suitable only for a speed of about 36 miles per hour.

The writer believes that very seldom has a line received such thought and study regarding the main questions of location — the economic questions — and the author deserves great credit for laying it before the Society so fully. The writer regrets that time prevents him from going into the subject more thoroughly.

E. J. Beard, M. Am. Soc. C. E. (by letter). — This paper is dedicated primarily to the young and inexperienced, and, therefore, it is important to call attention to some statements and computations wherein the author, in setting forth some of the considerations which determined important steps, has evidently committed errors, the pointing out of which, it is hoped, will prevent some of the dedicatees from falling into the same mistake.

It is not true, as the author states and applies, that the "operating expenses vary directly as the train-mileage," for only a part of the total operating expenses is affected by the addition or deduction of one

or more trains. It is not necessary to enter into history to verify this statement, as all railroad engineers (and, for that matter, all operating officials) should be thoroughly familiar with the principles underlying, and so admirably set forth in, the work of the late A. M. Wellington, M. Am. Soc. C. E. While the percentage cost of each item of expense to the cost of a train-mile, as contained in Wellington's "Economic Location," is not strictly correct at this date (due to change in conditions), his tabulations can be quickly brought up to date by the application to them of the data found in detail in the reports of the various State Railway Commissioners, the annual reports of various railroads, or, sufficient for all practical purposes, from the work quoted by the author.*

Wellington states that some 50 per cent of the cost per train-mile is affected by an increase or decrease in the number of trains. While there is some variation, under ordinary conditions, in the cost of each item since Wellington wrote, his figure, 50 per cent, is not, at this date, very far wrong when the change (*i. e.*, the increase or reduction in train-miles) is considerable, but when such a small reduction in the number of trains is accomplished, as by the author on the road in question, it is doubtful if the change would amount to more than 35 or 40 per cent of the average cost ($1.08) per train-mile on the Louisville and Nashville Railroad.

The statement that he is conservative in adopting this cost per train-mile, and in justifying the statement by referring to the cost per train-mile on the Duluth and Iron Range and the Duluth, Mesaba and Northern Railroads, is hardly to be considered true after looking into the operating conditions shown by the statistics of these roads, coupled with a belief in the very different operating conditions of each. From the United States Statistics of Railways, before referred to, the percentage cost per train-mile of the four grand divisions, referred to the total cost of a train-mile, is as shown in Table No. 4.

TABLE NO. 4.

	L. & N. Percentage.	D. & I. R. Percentage.	D., M. & N. Percentage.
Maintenance of way	21	27	35
Equipment	22	27	25
Transportation	52	42	34
General	5	4	6
Totals	100	100	100

* "Statistics of Railways in the United States," compiled by the Interstate Commerce Commission.

This table shows that the excessive cost of maintenance of way and equipment (notably the former), compared with that of transportation, is excessive as compared with that shown for the Louisville and Nashville. Although the writer is unfamiliar with any of the roads named, it would seem evident that climatic and other conditions on the Michigan roads, compared with those on the Louisville and Nashville, are the cause. There is nothing in the paper to indicate excessive maintenance expense, and, no doubt, it will at least average with that of the system of which it is a part, which, it is ventured to say, varies little, mile for mile, in the items of expense affected by trains or engine, when the number of trains is equal.

There are seemingly several reasons why the average train-mile cost on the road in question, if it had been built on a 1-per cent maximum, should not be any higher than the general average of the Louisville and Nashville. One is that there are many items included in the cost per train-mile (which is merely the unit of the grand total of the operating expenses of a great system, and includes many items, such as general officers, general office forces and other expenses), which will not in any wise be affected by the addition of this small mileage to the total of the road. In other words, it is not reasonable to assume that, when the cost of operation per train-mile on 3000 miles of road is $1.08, the addition of 79 miles, over which is to pass the same average train-tonnage per annum, will increase the annual operating expenses by the annual train-miles on 79 miles at $1.08 per train-mile. What has been said indicates the wide reasoning necessary to be conservative, and to be so that something less than $1.08 would be likely to be in order. However, to show more fully the wrong results arrived at by the author, that figure will be used later.

The author states that it was "in no wise certain that the 1-per cent grade would be used as a helper grade." How, then, is he justified in recommending the expense of reducing the other two 1-per cent grades to 0.65 per cent? The truth, no doubt, is that, whatever the number of trains, they will (as far as it is safe for the engineer to go) practically all arrive at the foot of the hill loaded to require a helper, as the operating department will hold for full train loads, unless the unbalancing of traffic should occasionally require return of power to the other end — an exigency unsafe to figure on — and the only proper thing to do is to figure on pushing all the trains estimated to be required for the traffic to be handled. Again, why run the helper

engine 4 miles more than the length of the helper hill? It should not, and is not likely to, be done, as it would give 16 or 17 miles, say (with properly located sidings), as the length of the helper's round trip, instead of 24 miles, and for 8 trains per day, or, with half that number on Sundays, 46,104 engine-miles per annum. The author also wrongly states that 4 trains on the 0.65-per cent grade will handle the same tonnage as 6 trains on the 1-per cent grade, representing a decrease of $33\frac{1}{3}$ per cent in engine- or train- mileage, when the relation between the grades in this respect is a reduction of 27 per cent. While this is true, probably a reduction to 8 trains should be estimated on instead of the exact ratio, 7.3.

From the foregoing data is obtained the annual saving in operating expenses due to the reduction in the number of trains, as follows:

20 per cent of 20 trains (10 each way per day) $\times$ 35 per cent of \$1.08 $\times$ 79 miles $\times$ 39 days per year = \$40,492.87.

This sum, capitalized at 4 per cent, gives but \$1,012,322, a sum vastly less than that arrived at by the author.

In determining the effect the operation of the helper engine will have on transportation, maintenance of way, and equipment expenses, it would have been better to obtain the data from the statistics of the Louisville and Nashville instead of taking those of the Pennsylvania Company, where conditions of operation are distinctly different, and adaptable to but few roads in this country. In lieu of nothing better than the "Statistics of Railways," those can be used, which, no doubt, conform closely enough for the purpose to the conditions that would be encountered. Obtaining therefrom the following, as the percentage per train-mile of operating items affected for maintenance, equipment and transportation (except wages) gives:

Repairs and renewals of locomotives	7.3	per cent
Superintendence and general expenses	0.6	"
Fuel	10.8	"
Water	0.65	"
Oil and waste	0.35	"
Other supplies	0.2	"
Telegraphing and despatching	1.1	"
Total	21.0	per cent

It is no doubt true that the expense of these items, in the case of a helper engine, would vary somewhat from the general average of a road engine of the same pattern, but, in view of the severe and

erratic service required of the helper, it would probably be more than for a road engine.

The assumption that half of the maintenance-of-way expenses is due to engines alone is, to say the least, a crude method, if one stops to think of how the introduction of a helper would affect in any manner whatever most of the items making up the total of such expenses, except as to roadway, rails and ties. Probably something like one-half of that proportion of the rail wear due to trains is due to the engines alone, but that ratio does not, as assumed by the author, apply to any of the other items, and the most that can be charged to maintenance of way is something like the following:

Renewals of rails	1 cent,
Repairs to roadway	3 cents,
Ties	0.6 cent,
Switches and sidings	0.4 "
Miscellaneous	1 "
Total	6.0 cents,

or about one-half the author's estimate. The coincidence of the total of transportation, and maintenance of way and equipment about equalling the author's, of course, has no meaning. His erroneous reasoning would give an error of $\pm$ 25 cents per train-mile, or about 50 per cent in such a case as the Duluth, Mesaba and Northern. Summing up these items gives, as the annual cost of one helper engine with a double crew, the following:

Interest on $14,000, cost of helper engine, at 4 per cent	$560
Annual wages of crew	3,744
46,104 train-miles at 27 cents	12,448
Total	$16,752

This is somewhat nearer the annual cost of a helper engine, which, by the writer, is almost invariably estimated at $18,000 per annum, and, in view of the many non-estimable objections to the use of a helper, is none too large. To draw attention to what some of these non-estimable objections might consist of, take this 8-mile helper hill. It will be found in practice that 8 freight trains per day each way is about the limit of one helper's capacity on such a hill, and its use will tend to delay trains at the foot of the grade, delay meetings at other places, and generally interfere with the even operation of the road, in

comparison with what it would be if no helper were required. All these delays mean expense — fuel, wages and other concomitant items —and probably $20,000 would not be too high to estimate as the annual cost of this pusher; but this is not intended to decry the use of pushers. From these figures, the estimated cost of change, to lower the ruling grade, would be as follows:

Annual cost of a helper engine on the Cumberland-Clinch Divide, $18,000 capitalized at 4 per cent	$450,000
Construction cost of two tunnels	195,180
Interest on construction for one year, having no earning power during the construction of tunnels	140,000
Total cost of change to lower grade	$785,180

There are other increased expenses, due to a reduction in ruling grade, to add to this. One, often overlooked in estimating the saving in operating cost accomplished by the reduction in train-miles for the same tonnage traffic obtained by the reduction of ruling grades, is that this reduction increases the cost of operation per train over every grade plane the rate of which is less than the ruling grade. Stated in another way, the value of a foot of rise and fall varies with the ruling grade. An engine loaded for the higher ruling grade can proceed on any less grade at a speed equal to that attainable if loaded for the lower ruling grade, with the consumption of less fuel; or, in another way, like engines will require and consume more time over a given division after its ruling grades are reduced to a lower maximum than before the change, when loaded for the respective ruling grade, resulting in increased expense for all items affected by time. The result of disregarding this fact is that often the advantages and saving in operating expenses estimated on by the engineers are not realized, and, consequently, the expected decrease in cost per ton-mile is not realized, the operating department finding it necessary to decrease the engine rating below that indicated by the differences in ruling grades, in order to get trains over the division within reasonable time and with economy. Take the line under discussion: It will require from 15 to 20 per cent more time for a train, having an engine loaded for a 0.65-per cent maximum grade, to go from Saxton to Knoxville than it would for the same engine loaded for a 1-per cent grade. This, probably, would not affect train wages, in view of the shortness of the division, if operated as one division; and whether or not it is to be operated that way is understood as yet to be unsettled. But, no matter

how it is operated, time affects fuel, water, oil, etc., all of which will be increased from 15 to 20 per cent, and some other items not necessary to enter into here to affect the reasoning. If the cost of fuel, oil and water is, as has been assumed, 11.8 per cent, this gives an expense here (due to this condition) of 20 per cent of 11.8 per cent of \$1.08 × 16 trains × 79 miles × 339 working days = \$10,922.

\$10,922, capitalized at 4 per cent, gives	\$273,038
Increased cost (before obtained)	785,180
Total	\$1,058,218

This amount wipes out entirely the saving expected by the reduction of ruling grade. While but an approximation, this is not far from the truth, and, without a doubt, the President of the Louisville and Nashville Railroad certainly does not yet understand.

It will not be amiss to warn the inexperienced not to take literally all the author's remarks about smoothness of grade lines, by which he awkwardly expresses absence of rise and fall, which, though an important matter, is minor to that of ruling grades. Its value is readily estimated, and, to avoid a few feet more or less on minor grades, will not warrant a very great expense. Neither should he take literally the implication that it is easier to obtain the best across Missouri's northwest prairies than through Tennessee's mountains. Many who have had experience in both kinds of country will bear out the remark that the contrary is true. Titanic work is not the embodiment of good engineering, and the 40 per cent more rise and fall on the Missouri road, considered with the conditions of years ago under which it was built, together with its cost (perhaps \$15,000 to \$20,000 per mile, at present prices), as against \$69,000 per mile for the Tennessee road, does not, by any means, indicate better engineering on the latter. The elimination of the 10 or 11 feet more rise and fall per mile would not warrant, with like traffic, an additional expenditure exceeding probably \$2000 per mile giving a cost of from \$17,000 to \$22,000 per mile, as against \$69,000. An examination of a map of the country crossed by the Chicago-Kansas City lines shows their general direction to be across the drainage, and each valley is from 250 to 350 feet below the saddles of the ridges, thus approaching those of the author's road.

Walter Watson, Assoc. M. Am. Soc. C. E. (by letter). — While the general rules to be followed in making a location given by Mr.

Taylor are vital and quite full, the writer would extend them somewhat by making the first one read:

(1) Of not using at any point more difficult gradients, nor any greater distance, nor any more curvature, nor stiffer curves than the country actually requires.

The writer would also suggest the desirability of adding another rule, *viz.*:

(5) Of occupying, at all strategic points, as fully as possible (without otherwise injuring the location), all the available ground.

Many engineers do not fully appreciate the value of distance and curvature saved, nor do some seem to appreciate the fact that it is not always the line that shows the least construction cost per mile that is the cheapest, even to construct. As an illustration of the effect of distance and curvature the following experience is cited:

The writer recently had occasion to revise a projected location, made previous to his engagement, through a very crooked valley with high bluffs on each side. These bluffs placed seemingly insurmountable obstacles in the way of any location, except one which followed the general windings of the valleys, and, even then, quite heavy work was required. At one place, covering about 1½ miles of the original location, it was found, however, that by introducing two tunnels (of about 550 and 260 feet in length) a line could be located, with the same gradient, with lighter curves, with about 320 degrees less curvature and about 2170 feet shorter. Although the construction of the new line was more expensive per mile, it was actually about $9000 cheaper than a line on the original location would have been, besides being much less expensive to operate.

Without in any way seeming to criticise the location shown on Plate I, for which it is presumed there were most excellent reasons, the writer would like to ask if it was on account of lack of sustaining ground from the Bull Run side of Copper Ridge toward Lee's Ford (territory outside of the limits of the plan on Plate I), that the long détour around Copper Ridge was used, rather than a line up Beaver Creek from Open Valley, near the point P, and then passing directly under Copper Ridge by a tunnel to the Bull Run slope of the ridge, or whether there were other considerations entering into the problem? Plate I would indicate that possibly such a line, with the same rise and fall and gradient as the line located, and from 1½ to 2 miles shorter, but requiring an indicated tunnel about

2500 feet long, compared with one 2170 feet long on the line as located, might have been used, provided suitable sustaining ground could have been obtained toward Lee's Ford.

In regard to the suggested rule (5), it may be stated that there are often cases in difficult country where the line can be properly located, so that it would be extremely difficult for a rival company to construct a line through the same pass or valley, while a location, equally good in other respects, could be made, which would leave room for a rival to pass, and thus the situation would not be fully controlled. The complete control of such a pass, or valley, might add very materially to the value of the property.

. . .

William G. Raymond, M. Am. Soc. C. E. (by letter).—This paper is of the greatest interest to all those having to do with railroad location. There are one or two points that will perhaps bear emphasis. The first is the great value of the topographic charts of the United States Geological Survey. Time and again have these charts been used in projecting water-supply work. Time and again have they revealed reservoir sites and conduit routes which would have been entirely missed by the reconnoitering engineer. And, for the use of the railroad locating engineer, they are even more valuable, not only saving his time, but insuring, with the exercise of reasonable care and intelligence, the selection of the most feasible route between two termini by compelling the following of Wellington's precept, stated anew by Professor Taylor in his fourth emphatic suggestion, that the reconnaissance shall be of an area, not a line, and by furnishing a small-scale, bird's-eye view of the widest possible area in such a way that it may all be taken in at a glance, all seen at once, and be all at once before the engineer for study. The writer has used these charts for both railroad location and water-supply work, and has found them invaluable aids. The completion of the charting of the entire country cannot be accomplished too soon.

A second point is that the low grade line does not always mean the most expensive line even in first cost; that, in general, an economical location is one which adopts the lowest possible grades for the longest possible distances, and bunches the difficulties at a few points where they may be overcome most economically by heavy work or by pusher service.

A third point is the evidence furnished by this paper of the advance

of railroad location from a trade to a profession; from the "rule-of-thumb" methods of many years ago to the scientific methods of to-day; and this without reflecting on those great men who, early in the history of railroad building, saw the true relation between location and operation. Moreover, the paper emphasizes the necessity for taking time and spending money in the design of the road, and by design is meant location, and for doing the work over, revising and re-revising, until the best that can be done by the united efforts of all the engineering talent engaged has been accomplished.

One suggestion: The paper professes to be written for the young men. Therefore, from the teacher's standpoint, should not the qualifying adjective "capitalized" be used before "cost" in the paragraph on page 342.

One other suggestion: In determining the cost of pusher-engine service, only those items of expense which may be attributed to this particular service are used, a proceeding that seems rational; but, when it comes to a consideration of the saving due to the reduction in train-miles by the lower ruling grade, it is stated that "operating expenses vary directly as the train-mileage," the cost per train-mile on the Louisville and Nashville Railroad for the year 1902 is used in the calculation following, and the total saving is found by multiplying the train-miles saved by this train-mile cost, $1.08. This, being the average cost of all trains, is, of course, as the author points out, not the proper cost to apply to the heavy freight trains, the ones affected by the grade changes considered, but is used for safety, the actual cost of trains not yet running being indeterminate. The author estimates that the average train-mile cost of these heavy trains may be as great as $1.50; but, whatever it is, will the saving in money, due to a saving of train-miles, equal the cost per train-mile multiplied by the train-miles saved? Manifestly, it will not, and a considerable part of the late Mr. Wellington's great work was devoted to showing that it will not be this quantity. Railroad bookkeeping may make it so appear, and an increased number of trains due to increased business does not always seem to lessen the train-mile cost, as it should, theoretically, but this is due largely to increased expenses warranted by the increased business, and is not at all due to the greater number of trains. In recent years train-mile cost has increased greatly, but this is not due to the running of more trains. When the business does not change, and a reduction in train-miles, due to a reduction in grades,

or increased locomotive power, is secured, it is doubtful if more than half the average train-mile cost is saved for each train-mile saved. Just how much the saving is, no one knows. In the present case, if $1.50 per train-mile is a fair cost for the trains affected, and half of this can be saved with each train-mile saved, the annual saving will be $80,343, instead of $116,000, and the amount gained by the changed line will be $1,327,420, instead of $2,218,845. The reduction of nearly $900,000 in the capitalized saving in no wise changes the correctness of the final choice in this case, but it might well change it in some other case where the difference in values might not be so great. With an assumed train-mile cost of $1.50, it is entirely possible that each train-mile saved may mean $1.08 saved, but the evident purpose of the author was to use the whole train-mile cost, making only as much allowance as would insure his being within that cost.

Whether or not the suggestion here made is wise, may be a matter of opinion; it outlines the procedure the writer would follow.

With this change, and possibly without it, the paper seems to be one of the most valuable that has recently appeared for the study of the young engineer.

F. Lavis, Assoc. M. Am. Soc. C. E. — The speaker thinks that it was unnecessary to offer any apology for the presentation of this paper on account of the fact that the perusal of it might be loss of time to some experienced engineers. An engineer who is interested in railroad location as a science cannot fail to be interested in the development of such a low grade line through a very rough piece of country. The speaker does not feel sure that the low grade was warranted, but will refer to that later.

The literature on the practical aspects of railroad location is chiefly conspicuous by its absence, and a description of this kind, of actual work performed, is therefore valuable. It would have enhanced the value of the paper considerably had the author been able to go into more details of the work, even at the risk of saying something which might have been known to someone else, and to have shown, if possible, a map of the various preliminary lines run and their relation to the final located line, and to have given some details of the cost of the surveys and the time consumed in making them.

Mr. Taylor states as his fourth principle, in making such surveys as this, the necessity of making "a diligent study of the whole country." Evidently, he did this before the completion of the work,

but fuller details of how much country the reconnaissances covered, how much time was spent on them, and how the final results were deduced from these observations, would have been invaluable, to experienced engineers as well as to students.

It hardly seems possible that railroads to-day are located in any other than a big, broad-minded way, with time and money enough to do the work thoroughly, and to thrash out the country until absolute proof is obtained that the best line has been selected.

The speaker, however, knows from a rather extended experience that, in spite of all that should be known of the increased cost of operation of badly located roads, many miles of railroad are being located and built now in the same old narrow-minded way, and this is the cause of the large expenditures which are being made for relocations and revisions. Many men, investing in railroad projects, still believe that any money spent on engineering, and especially on location surveys, is just so much money wasted.

An instance has come under the speaker's observation recently. On what is now part of a trunk line, and between two points, about 200 miles apart, by the present operated line, a new line has been located, saving more than 30 miles of distance, with ruling grades of one-half of those on the older line, saving nearly 3000 feet of rise and fall, and having less than half the total degrees of curvature of the older line. This does not necessarily imply a criticism of the older line, as the speaker does not know any of the conditions under which it was located and built or the relative cost of the two lines, but it illustrates what can be accomplished by a thorough study of the country and by properly conducted surveys.

It seems strange that the author has offered no explanation of the fact that so many changes were necessary after construction was started. It appears that the route had been under consideration, more or less, for the past twenty years, and surely, at least a decision as to ruling grades and the general location of the line, if not of the minor details, should have been reached before construction was commenced.

It is stated that, when it was found that 0.65-per cent grades could be obtained on this new line, this required changes in minor grades on the part on which construction had already started, and caused the officials of the Louisville and Nashville to determine to make some grade revisions on the old lines which this link connected.

Surely this new line and the whole freight division of which it is a part should have been studied as a whole, to determine the ruling grades possible on the whole division, and a thoroughly comprehensive survey should have been made before construction was started.

One of the grave errors, even to-day, in a great deal of the grade revision, is that it is not comprehensive enough, and the work is done in little pieces.

It does not necessarily follow that, because a comprehensive scheme has been laid out, the work has to be undertaken all at once, but the work done should be governed by its relation to the whole.

It is hardly possible, from the information contained in the paper, to estimate the value of the change from the 1-per cent to the 0.65-per cent grade on this short piece of line, without knowing its relation to the operating division of which it will form a part.

In speaking of the rates of grade, the author uses indiscriminately rates per mile and rates per cent. Rates of grade in this country, at least among engineers, are now spoken of almost exclusively in rates per cent, and it would seem advisable to use this method of nomenclature exclusively, at least in an engineering paper.

In reference to the Missouri prairies: The word, prairie, generally conveys to the average reader an idea of a comparatively level plain, but some of the most difficult location can be found through the Missouri and Iowa prairies, especially for low grade lines. Mountain ridges may be bucked through, but the long rolling country, with differences between ridges and valleys often amounting to more than 200 feet, such as found through Missouri, broken up by cross-drainage, presents some of the most difficult problems in railroad location. The line has to go down into valleys and over ridges, and the slopes are almost always just too steep for the grades one is trying to get.

W. H. Coverdale, Assoc. M. Am. Soc. C. E. — The author is to be congratulated, both upon his location of the line between Knoxville and Jellico, and upon his description of the work. The locating engineer always delights to narrate his troubles; but, unlike the author, he does not always succeed in making the narration attractive.

The topography of this section of country, as may be seen from a glance at the map, is enough to strike terror into the heart of the engineer who is looking for a railroad of easy grades and tangential alignment between the points named.

Not only does the backbone of the Cumberland Range interpose a

rugged barrier some 500 to 600 feet higher than either terminus, but series of subsidiary ridges, parallel to the axis of the mountain and divided by deeply-eroded valleys, point their forbidding fingers across the path; and precipitous torrents, at widely-varying elevations, roar their challenge of defiance.

The author, in all probability, has secured the best location which the country — and his company — affords. He states frankly that the grade reduction, which left one pusher grade on the road, was an afterthought, considered only when much construction work had been done; hence the relation between the maximum ordinary and pusher grades needs no criticism. All in all, the result of his work can be but a matter of congratulation. The method by which the result was secured is the subject matter of this discussion.

In any topic as comprehensive as that of railroad location, much of interest must necessarily be omitted from a paper, which the author does not intend as an exhaustive treatise; and, indeed, the author states that he has not mentioned that part of the work upon which he spent most of his energy. This probably means the reconnaissance feature, as he emphasizes the importance of a diligent study of the whole country; and if this assumption be correct, an ignorant, but interested, reader of the paper would respectfully ask that, before the discussion be closed, the author give some idea of the amount of such work which was necessary in the development of this line. A thorough reconnaissance and the method of selection of the primary points on the route is not a narrow and detailed question, but a broad determination of policy upon which must rest the vindication of the located line. The fact that the author speaks definitely of the features of Copper Ridge for a distance of 30 miles from the point where he crossed it throws a little light on the scope of such work.

About seven years ago the speaker drove more than 20,000 miles, looking for a 20-foot-per-mile grade for the Pittsburg, Fort Wayne and Chicago Railway, between the Ohio River and the prairie country, some 200 miles to the westward, and he recalls the narrow and prejudiced state of mind in which he was when he began the work. A summit, lower than the one over which this line was laid, and in plain sight of it, meant nothing to him but that the locating engineer had been in error, while a détour of 10 or 50 miles, if it afforded the required grade, was the one route which should have been considered seriously. Such matters as excessive cost of construction, failure to

serve important centers of population, greatly increased mileage, etc., were mere bagatelles when weighed against the reduction of ton-mile cost.

However, a little good advice from his chief engineer soon put him in a more tolerant attitude, and he began to realize that topography is but one of several factors, and too often an unknown one at that, in the transportation equation.

This suggests a second point to which the speaker wishes to call attention, namely: Men of a previous generation must not be judged by present standards, and this is equally true of technical skill and of morality. Who shall say that the old Portage Road across the Alleghany Mountains was not the proper answer to the stage-coach problem? Who shall say that Hernando Cortez and Nero were cruel men?

The author compares his grade of 34 feet per mile with that of 66 feet per mile existing on rival roads. He also states that his total average rise and fall per mile is only 21.5 feet, as against 59.2 feet for the old road. He states, further, that his road is smoother than an unnamed prairie road by 42 per cent. These facts are pertinent and interesting, but they are disjointed, or, rather, isolated; and, in all fairness, the inference that the first railroad through this country should have been constructed on the location described by the author must be avoided.

Many other facts must be added to those stated by the author before the chain of cause and effect can be completed, as, for instance, the cost per mile which secured the 34-foot grade, as against the cost of the 66-foot grade, the length of the respective routes which exceeded the straight-line distance by 34 and 55 per cent in favor of the old route, and the general traffic and commercial conditions obtaining at the respective dates of construction.

Because men built railroads on a 1-per cent maximum grade fifty or twenty years ago, it by no means follows that they built badly, and their work must not be judged by the conditions under which work is done to-day. Increased traffic, competition, reduction in ton-mile revenue and other considerations to-day make easy gradients imperative and economic, which, a generation ago, would have been the height of folly; and it may even be possible that this "widow's mite" railroad, running up and down and across country, over the hills and hollows — on which, it may be, the old rails have a hard time

to keep the fire-box off the ties — may have represented as nice an adjustment of means, methods and results as the author's modern road.

In regard to grade revision and the method of determining the amount which could be spent economically for tunneling, it is noted that the author's estimates are based upon a 2170-foot tunnel at Copper Ridge and a 700-foot tunnel at Black Oak Ridge No. 2. The actual construction work, however, was not carried out on these lines. The town of Clinton, with its contiguous 700-foot tunnel, was weighed in the balance against the town of Dosset and the claim of the Oliver Springs Branch, and found wanting, and so a sweeping change of location was made and a tunnel 3520 feet long was substituted for the 700-foot tunnel.

The total length of main-line tunnel, therefore, is 5690 feet instead of 2870 feet, or practically double the length used in estimating. It is beside the question to offset the additional cost of main-line construction against the saving on the branch line because main-line construction cost must be justified by main-line traffic results.

Furthermore, although by this plan the grades on the branch line were reduced to the main-line ruling grade against south-bound traffic, and although, theoretically, this is very nice, yet grades of coal branch lines are by no means as important as main-line grades, and for several reasons:

(1) Through main-line freight trains do not travel over such branches, nor stop at such junction points to take on loads or set off empties, except in rare instances.

(2) Trains running light and filling to capacity at local points are rarely a factor in grade determination.

(3) Local trains deliver empties to mines and collect loads therefrom, and seldom work up to full engine capacity.

(4) Coal branch grades are with, rather than against, their traffic, and a grade of 34 feet per mile, over which to shove merely empty gondolas, is an expensive luxury.

It appears, therefore, that the author's estimate of what the 34-foot grade would cost should have included all main-track work as actually built. Since it is not apparent from the paper what the increased cost of the 5690 feet of tunnel is over that portion of the original line which it displaces, it would not be pertinent to subject the author's estimate to detailed examination.

It is pertinent, however, to call attention to the idea which pervades the argument expressed on page 344: "Operating expenses vary directly as the train-mileage," and to be satisfied that this premise be a sound one before accepting the conclusion.

The *Transactions* of this Society contains a memorial of that great railroad economist, Albert Fink; * and even from those brief notes may be learned the fact that his first analyses of railroad operations were embodied in the annual reports of the Louisville and Nashville Railroad about thirty years ago.

Mr. Fink's writings upon this subject are still classics, and it is of interest to note that the officers of the very railroad, the records of which contain so much that is practical and scientific, acquiesce so readily in the empirical theory which the author states as a fact.

Revenue train-mileage is a unit of service by which may be measured the cost price of transportation. To say, however, that this cost price varies directly as the total amount of transportation sold, is to disregard all the primary-construction cost of the property, much of the maintenance, and a considerable amount of the costs incidental to train service and general expenses.

The Interstate Commerce Commission classifies railroad operating expenses under four main headings:

1st. Maintenance of way and structures,
2d. Maintenance of equipment,
3d. Conducting transportation,
4th. General expenses.

A brief examination of these expense items will show to what extent they vary as train-mileage:

(1) "Maintenance of way and structures expense" "fluctuates, not with the rate of wear, but with the rate of renewal," says Mr. Eaton, the statistician of the Lehigh Valley Railroad, in his book on "Railroad Operations." The character and amount of traffic determine in a general way the types of track and bridge structures, but large sums are spent annually for maintenance of such structures, and appear in the figures which the author has used, which have nothing whatever to do with train-mileage.

Widening banks, sodding slopes, cutting weeds, repairing fences and track signs, many tie renewals, painting bridges and buildings, renewing bridges and buildings destroyed by fire, flood, or lawless-

* *Transactions*, Am. Soc. C. E., Vol. XLI, p. 626.

ness, the substitution of steel and masonry for wooden structures, grade reductions, revisions of alignment and other betterments of magnitude not chargeable to capital account: All these items of operating expense depend in no way upon the train-mileage.

The "maintenance of way and structures" item, for the Louisville and Nashville Railroad, amounted, in 1902, to about 22 per cent of the entire charge against operation; and, of this amount, only $33\frac{1}{3}$ per cent, or 7 per cent of the whole, is chargeable to train-mileage. This apportionment is made on the basis of the Pennsylvania Railroad methods, and includes all renewals of rails, frogs and switches, $33\frac{1}{3}$ per cent of cross-tie renewals and 10 per cent of repairs of roadway, track and bridges. All repairs of buildings, docks and structures, other than above, are taken as independent of train-mileage.

(2) "Maintenance of equipment expense" varies with engine-mileage, freight and passenger car-mileage, but not with train-mileage. It depends upon alignment and grade of line, weather, speed and accidents; it includes cost of marine-equipment maintenance, interest on shop investments, etc. This item, for the Louisville and Nashville Railroad, amounted, in 1902, also to about 22 per cent of the entire charge against operation, and cannot be said to vary directly with train-mileage. It is noted that, while repairs to locomotives, passenger and freight cars, etc., are the direct result of operation, yet a unit of maintenance, much more exact than train-mileage, is now in general use.

(3) "Conducting transportation" is usually subdivided into twenty-five or more accounts, including fuel, water, locomotive and miscellaneous supplies, wages of engineers, firemen and roundhousemen, switchmen, flagmen, station supplies, advertising, telegraphing, car-mileage, injuries to persons and property, etc., etc., and only one of these accounts, namely, train service, which covers the wages of conductors, baggagemen, brakemen and flagmen, can be said to vary directly with train-mileage. This item, for the Louisville and Nashville Railroad, amounted, in 1902, to about 52 per cent of the total operating expenses, and of this amount only 13 per cent varies with train-mileage.

(4) The item "general expenses," of course, does not vary with train-mileage, so that, in all, about 14 per cent of operating expenses depends upon train-miles run, and upon this slender thread hangs all the weight of the author's argument.

W. D. Taylor, M. Am. Soc. C. E. (by letter). — The writer congratulates himself that, with possibly a single exception, this paper has met with so fair and frank a discussion.

Many of the points brought forward are suggestive, and the writer regrets that there could not have been time and opportunity for a discussion of this nature during the lay-out of the work.

Engineers connected with railway work have been slower, perhaps, than others of the profession in abandoning, toward their own work, the old unscientific attitude, which maintains that "it's right because I fixed it so." A prominent railway president, of a western road, who is not an engineer, insisted, not a great while ago, in conversation with the writer, that even now they were making small progress in this direction.

Though no engineer can project a work of this magnitude, which involves as many conflicting elements as extensive railway location in difficult country always does, and which is laid out in the hurry that was unavoidable in this case, and feel absolutely sure that serious errors have not been made, yet, the writer trusts that no really essential element was overlooked in this lay-out.

Before discussing the questions raised by the writer's critics, a few points not included in the paper will be mentioned.

A letter of instructions, as to their duties, sent to all resident engineers on construction on this line, may be found in *Engineering News*.*

Clauses in the specifications for construction which vary somewhat from the usual forms were as follows:

"Stumps shall be grubbed for 2 feet back from the slopes of cuts, from ditches, and from new channels for waterways.

"Clearing shall be paid for separately. Grubbing shall be paid for in the price paid for excavation.

"The price paid for clearing is understood to apply to the heaviest clearing to be encountered along the line. When the clearing is lighter, it is to be rated by the engineer, so that at a point where only half the work done on the heaviest sections is necessary it shall be rated accordingly.

"Embankments shall not be built with wheel-barrows, grading machines, or by casting, or by any process which does not thoroughly

*March 5th, 1903, page 217.

pack the material. Dump-cars may be used only on very high fills and upon the special instructions of the engineer.

"All embankments shall be kept to the full width of cross-section at all heights while being built, with the sides at least as high as the center of the roadbed.

"In constructing any embankment, except one built of hard rock material, no back dumping from carts is to be allowed, but the embankment is to be built either in 6-inch layers or less, or to be so sloped that the teams will constantly pass over all material as soon as it is dumped."

These restrictions as to the manner of building embankments did not seem to have a very ill effect on the construction prices, as will be apparent from an examination of the contract prices given in Table No. 5. The excavation was all paid for as measured in excavation, with a free average haul of 500 feet. The overhaul clause reads as follows:

"Average haul shall be computed for each cut separately, and short haul from one cut shall not offset long haul from another cut. The average haul from any cut shall be the distance between the center of gravity of that cut and the center of gravity of the fill which the material from that cut makes."

The two branches and the work on the main line north of La Follette were let to one firm of responsible contractors; the work from La Follette to Beaver Creek to another; and the work from Beaver Creek to Knoxville, and including the Knoxville yards, was let to another. The price of ordinary labor, most of which was done by negroes, varied from $1.00 to $1.35 per day.

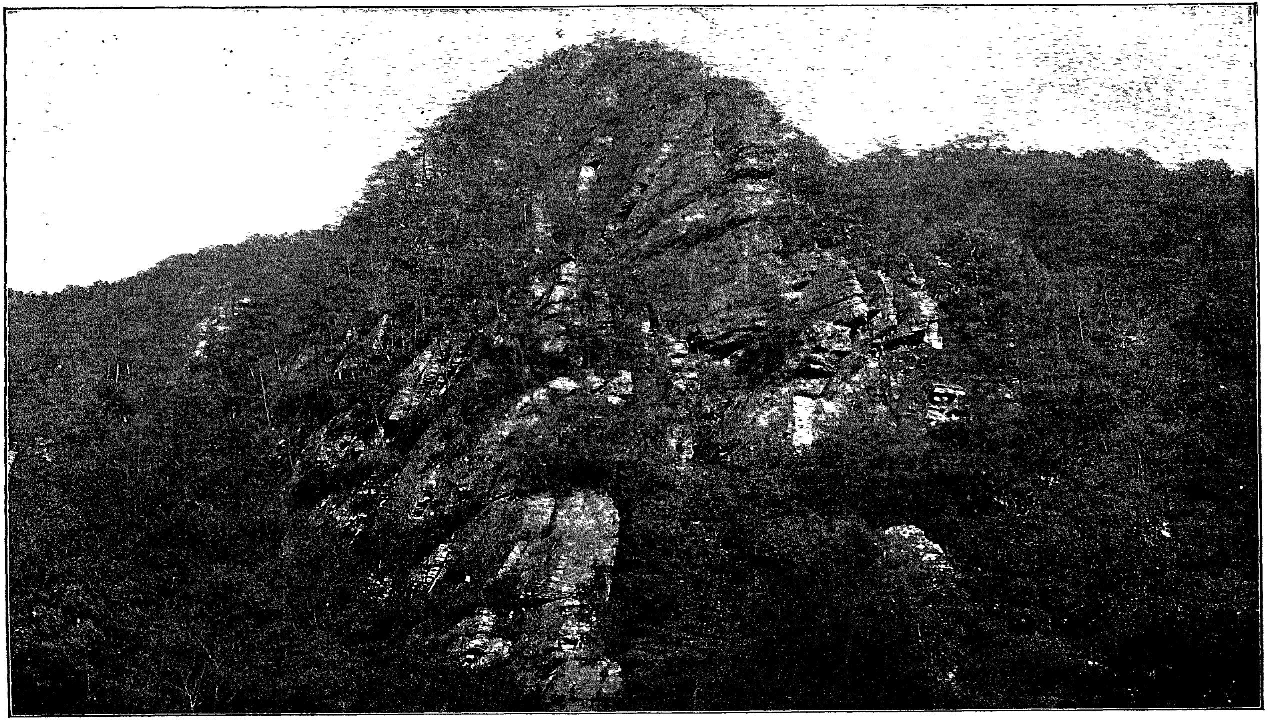
The prices paid in the contracts varied between the limits given in Table No. 5.

Timber and stone were fairly well distributed on all the lines north of La Follette. Suitable timber was, for the most part, white oak, which was too small for trestle stringers. South of La Follette all timber, except that of a very temporary nature, had to be imported, and stone for masonry was not very well distributed. For example, the stone for the masonry of the Clinch River Bridge had to be brought in barges from near Clinton. No transportation for either freight or passengers was allowed on the Louisville and Nashville. Portland cement of the better brands was worth $2.85 per barrel in Knoxville.

TABLE NO. 5.—CONSTRUCTION PRICES ON THE KNOXVILLE, LA FOLLETTE AND JELLICO RAILROAD.

Clearing, per acre	$18.00	$20.00
Earth excavation, per cubic yard	0.17	0.19
Loose rock excavation, per cubic yard	0.35	0.37
Solid rock excavation, per cubic yard	0.67	0.70
Chert excavation, per cubic yard	0.28	0.28
Water excavation, per cubic yard	0.75	1.50
Tunnel excavation, per cubic yard	2.50	3.00
Iron, in trestles and foundations, per pound	0.04	0.04
First-class, stone, bridge masonry, per cubic yard	8.00	10.50
First-class, stone, arch masonry, per cubic yard	10.00	11.00
Stone, culvert masonry in natural cement	4.50	5.50
Stone, culvert masonry, laid dry, per cubic yard	3.25	4.50
Rip-rap, per cubic yard	1.00	1.50
Stone paving (in culverts), per cubic yard	1.50	2.00
Concrete in foundations, Louisville cement, per cubic yard	4.25	6.50
Concrete in piers and culverts, Portland cement, per cubic yard	6.75	7.50
Concrete in arches and walls, Portland cement, per cubic yard	6.75	7.50
Temporary trestles, per 1000 feet, B. M., including iron	15.00	17.00
Concrete packing in tunnels, natural cement, per cubic yard		6.00
Dry packing in tunnels, per cubic yard	1.50	2.25
Piles in foundations, per linear foot	0.40	0.50
Timber in foundations, per 1000 feet, B. M	24.00	27.50
Piles in pile bridges, left in work, per linear foot	0.40	0.40
Pile trestles exclusive of piles and stringers, per 1000 feet, B. M.	28.00	28.00
Framed trestles, per 1000 feet, B. M	28.00	28.00
Timber in tunnels, left in the work, per 1000 feet, B. M.	27.50	28.00
Hauling drain pipe, cement, or other construction material especially aranged for, per mile per ton	0.35	0.44
Overhaul, per cubic yard	0.01	0.015
Necessary haul on masonry stone, per cubic yard per mile, after first mile	0.75	0.75

There have appeared in the discussion so many inferences which were contrary to fact, even though they were seemingly warranted by some of the writer's awkward expressions, to one of which Mr. Beard calls attention, that it would seem to be well for anyone who wishes to make a special study of this location, and whose impresisons as to the facts are not cleared by the closure, to inspect the topographic sheets of the Geological Survey covering the area traversed by the road and its branches. They are the Williamsburg, Briceville, Loudon, Knoxville, Cumberland Gap and Maynardsville Sheets. In



Rockhead in Big Creek Gap through Cumberland Mountain.

order to give a more adequate idea of the character of the country and of the work, a few photographs, Plates II, III and IV, have been inserted.

The discussion by Mr. Low in regard to the Clinch River Division of the Norfolk and Western is particularly interesting to the writer. This discussion, taken in connection with his discussion of the paper "Heavy Railway Construction in Wyoming," * seems to warrant the assertion that it is not possible to escape expensive work in this territory, even when using 90-foot grades in both directions, temporary structures, and when running generally with the drainage. No doubt the topography at and near the headwaters of the Clinch is somewhat rougher than along the Knoxville, La Follette and Jellico, but the latter country is of the same general character as the former, and the Knoxville, La Follette and Jellico was built with permanent structures, with very much lighter gradients, and generally across drainage. The line of the Knoxville, La Follette and Jellico lies very low, relatively to the adjacent country. A gravity-supply water station, ample throughout the year, was easily available right on the summit of the Clinch-Cumberland Divide, the highest point on the line.

The writer does not know what the cost per mile of the Knoxville and Ohio Branch of the Southern would be, in existing condition, and, judging from his experience in railway appraisals, is quite sure that no one else does. But the line has the same number of tunnels as the Knoxville, La Follette and Jellico, two of which are quite long, and has a quantity of quite heavy construction. The line probably could not be reproduced with properties new and with permanent structures at a less cost per mile than $40,000, exclusive of terminals and equipment.

It is no doubt due to another of his awkward expressions that the writer's critics have gotten a somewhat exaggerated idea of the expensiveness of the line. The cost data for the main line, given on page 352, includes the cost of expensive terminal lands, yards and station buildings within the City of Knoxville. The detailed figures are not at hand, but probably between 20 and 25 per cent of the total amount will be expended within the limits of that city.

Further, by far the costliest part of this line, barring the construction of the tunnels, which have received so much attention, was at the head of the Narrows and along Hickory Creek, just south of the

* *Transactions*, Am. Soc. C. E., Vol. XLVI, p. 17.

Narrows, where there was only one route possible, and where there was no question whatever concerning gradients.

The writer would gladly accept Mr. Walter Watson's suggested change and interesting addition to the rules outlined for location work, also Professor Raymond's suggested change in verbiage.

The writer is quite sure Mr. Coverdale did not catch the import of all the reasons given for the change of the location from the route *via* Clinton to the route *via* Dosset. The main line, itself, was shortened nearly $\frac{1}{2}$ mile by that change, and the alignment very much improved, in addition to the other advantages explained.

Not one cent was expended to secure 34-foot grades on the branch lines over which to shove empty gondolas.

There is no doubt, as some of the writer's critics have suggested, that parts of the road were put under construction too soon, before a definite detailed policy of development had been decided upon. There were such urgent reasons for haste in some of these matters that grading forces were put on parts of the line before all the surveys were connected, the reasons for which can be easily divined by the initiated.

Since the writer has seen so much adverse grade used, which could have been excluded at no expense at all, but by the exercise of a reasonable amount of care, he confesses to personal antipathy to such grades. Although all that Mr. Watson says, in regard to using undulating grades with sags dropping from 30 to 40 feet below a generally level gradient, is true enough, the writer suggests that the evil effects of an adverse grade can hardly be over-estimated in the lay-out of a road for slow and heavy traffic on long ascents where the grade rate is the maximum or approaching the maximum; that is, where the gradient exceeds, for the slowest and heaviest trains, Class *A*, of Wellington's classification. The evil effect of such an adverse grade consists, for the most part, in that, wherever it is possible, the total elevation could be surmounted with a uniform gradient of less rate.

The grade profile shows that in comparatively level country, where the vertical elevations surmounted were not so great but that momentum could be used effectively in surmounting hills, adverse grades were permitted in order to reduce the cost of the work. But on long ascents on the steeper gradients momentum grades have no place, and, in such cases, adverse grades were excluded.

One of the writer's critics contends that, as the natural drainage

Fig. 1.—Beginning Construction, Jones Bluff on Copper Ridge.

Fig. 2.—Masonry at Hickory Creek Crossing No. 3; and North Portal of Tunnel No. 2.

PLATE III.—Trans. Am. Soc. Civ. Engrs., Vol. LII, No. 977.
Taylor on "Railroad Location."

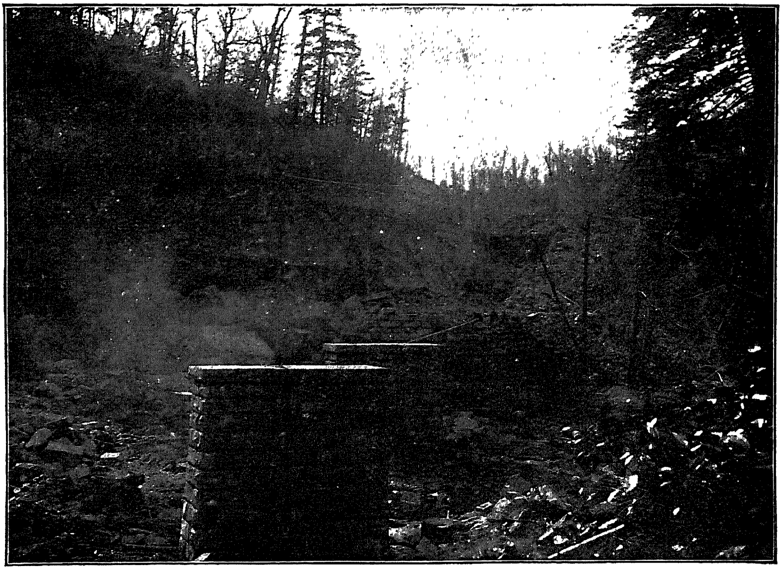


Fig. 1.—Masonry, and Rock Excavation, Hickory Creek Crossing No. 7. Looking South.

Fig. 2.—Masonry, and Rock Excavation, Hickory Creek Crossing No. 7. Looking North.
(This line goes through the edge of the precipice.)

route from La Follette to Knoxville led down Big Creek and the Clinch to Clinton, that route should have been followed. One of the usual consequences of leaving a natural drainage route in railway location is adverse grade, and the amount necessitated on the original line between La Follette and Clinton was cited by the writer to show the extent of the penalty paid, which amount, though large enough at one point to be both objectionable and expensive, seemed to be warranted by the advantages secured. Besides, . . . the line followed a natural drainage route for the first few miles south of La Follette, while the stream, Big Creek, followed a route which in one sense might be called artificial. To the writer, the reasons given for the selection of the route between La Follette and Clinton, on the original location through Clinton, seem conclusive enough. The location that Mr. Low describes also left the natural drainage route. And the penalty paid in this case was, not only adverse grade, but the introduction of a grade of 90 feet to the mile, and it was the only one on 100 miles of road exceeding 58 feet to the mile, opposing the direction of probable heavier traffic. This is certainly very objectionable, but without opportunity to make a careful investigation, the writer would be slow to say that the location made was ill advised, for conditions, and not merely theories, are to be dealt with in railway location everywhere, and especially in country of the Clinch River variety. If the river line was taken, the locating engineer on Mr. Low's road was probably confined, on Clinch River between Sword's Creek and Cleveland, as the writer was on Big Creek below La Follette, to a choice between a crooked and expensive line, unduly lengthened from following the windings of a tortuous mountain stream, and a more direct line, constructed for the most part in tunnels and on bridges.

The primary object in the location of this line was, not to reach Knoxville, though that was of great importance, but to effect through connection with the Atlanta, Knoxville and Northern to the South. The road enters Knoxville on the northwest side of the city, passes through the western edge of it, and effects the junction with the Atlanta, Knoxville and Northern at the southwest edge of the city where large freight yards are provided for, and then runs northeast and north $1\frac{1}{4}$ miles to the center of the city, where are the city freight and passenger yards and stations. Thus, through freight will pass only through the western edge of the city. If the through route had been established *via* the line now occupied by the Southern it would

have been, on this account, 8, and not 11, miles shorter. If the route had been laid out on 1-per cent compensated grades, *via* the general route now held by the Southern, retaining the present crossings of valleys and summits, and putting sufficient development into the line to gain the necessary elevations, that route would have been lengthened enough, between Clinton and Knoxville alone, to account for all but $1\frac{1}{2}$ miles of the present difference in length. The cost of laying out a road through the district, on the general route occupied by the Southern, on compensated grades of 1 per cent south-bound and 1.15 per cent north-bound would not be warranted by any traffic that any road in the district can reasonably expect for years to come.

Further, the Atlanta, Knoxville and Northern runs southwest out of Knoxville, while this road, from the point, *P*, in the open valley of Beaver Creek, runs in a general direction due east 14 miles to the Atlanta, Knoxville and Northern connection at Knoxville. From this point, *P*, to a point immediately south, 12.5 miles distant on an air line, and 19 miles below Knoxville on the Atlanta, Knoxville and Northern there is an excellent route available, under the same restrictions as to gradients, but which route involves the construction of a tunnel under Black Oak Ridge and a bridge over the Tennessee River. This cut-off (say, 15 miles in actual length) would shorten the through route at least 17 miles, and there was little doubt in the writer's mind that the traffic of the road at no very distant day would warrant its construction. The probability of the eventual building of this cut-off had its due share in the decision on the present route south of Coal Creek.

By some heroic construction, between 2 and 3 miles of distance could be cut out by the plan, very pertinently suggested by Mr. Walter Watson, of cutting out the development at Copper Ridge. That the necessary tunnel to carry out his suggestion would be very much longer than he estimates is due to the fact that the part of the map on Plate I, at the extreme up-stream end of Beaver Creek as shown, is a mere sketch, and is inaccurate. The north side of Copper Ridge is precipitous and badly broken, particularly at the elevation at which such a line would strike it, and, though there is some, there is a dearth of, supporting ground up the Clinch toward Lee's Ford, as may be seen from Plate I. When the traffic of the road warrants the building of the cut-off mentioned above, it may be that this revision may also be warranted.

The element producing the greatest doubt in the writer's mind as to the advisability of reducing the south-bound grades has not been mentioned by any of his critics. If the original location on the 1-per cent grades should have been retained, then, in the writer's opinion, it should have been done on account of the commercial and operating value of an early opening of the road, rather than because the immediate expenditure to effect the reduction was not justified by the results to be gained. Certainly, the value to the system, of this link which should unite its separated parts, for the period through which the opening of the road was necessarily postponed by this reduction, was very much more than the bare interest on the capital already expended in construction.

The writer wishes to say that the general officers of this road were in no wise misled. The President of the Louisville and Nashville Railroad seems not to believe that he needs an engineer to advise him as to the operating value of a given grade reduction on any part of his system, and, in the writer's opinion, that belief is wonderfully well founded. He never saw the figures which give alarm to two of the writer's critics, but when he saw the figures as to what the reduction would cost, the writer still thinks he fully understood. Every important step in the lay-out of the road was fully discussed with the Chief Engineer of the Louisville and Nashville, and with other engineers who knew their business. Even if custom on railways permitted, it is doubtful if any one man ought to undertake to decide important steps in expensive and extensive railway construction, without full and free discussion with several traffic and construction experts.

It is true only in a very broad sense that operating expenses vary as the train-mileage. This paper was prepared in moments snatched from very exacting work, but within a very few days after the paper had been accepted for publication the writer noticed the error he had fallen into, and to which several of his critics have called attention. The calculation as to the value of the grade reduction was made anew, and, as the corrections were needed for the most part only in the figures, the writer held them, intending to make the necessary changes in the proof, which he, not being familiar with the mode of procedure in the Society's publications, expected would be sent to him.

Now the saving that can be effected in operation by cutting down grades on a division which has been operating, say, 20 trains per day, so that the same business can be done by 16 trains, is a very different

matter, for the first few years at least, from the saving that can be made in future operating expenses in constructing a road to do its business with 16 trains per day instead of 20. Every railroad manager knows how utterly impossible it is, when business falls off and the number of trains is reduced, to reduce expenses accordingly. The impossibility of accomplishing this is due primarily, but not entirely, to the fact that an organization equipped for the more expensive operation of 20 trains per day is now retained to operate a less number. The grade of service as to men, equipment, maintenance, etc., necessary to operate a division handling 20 trains a day is very much above the grade of the same required for 16 trains. When the number of trains is actually decreased in operation the more expensive organization is already in existence and will be dispensed with only with great difficulty and after long years, if indeed an increase of traffic does not warrant its retention. But in laying out a new road to handle its business with 16 instead of 20 trains per day the more expensive organization to operate 20 trains per day will not be developed.

This was the thought uppermost in the writer's mind. But its fallacy consists in the fact that a grade reduction is for all time, and the grade of the service, eventually, will be adjusted to the demands of the traffic.

Since this paper was prepared, this subject has been treated exhaustively in a paper* by Mr. J. B. Berry, Chief Engineer of the Union Pacific Railroad. Mr. Berry's analysis of the percentage of operating expenses on an operated road which can be saved by cutting down train-mileage through grade reduction shows a result of about 44. This is the lowest result that has been attained by any adequate analysis that the writer has seen, but, even if only this saving can be made by the grade reduction, it still was advisable, as Mr. W. P. Watson and Professor Raymond conclude.

The writer thinks there are good reasons for believing that Mr. Berry's and Mr. Watson's analysis of this percentage may not be quite conclusive in this case. For instance, in calculating the proportion of operating expenses on which savings could be effected, both Mr. Berry and Mr. Watson assume that there would be no reduction in telegraph nor general expenses. Twenty trains per day will probably call for more train-order stations than sixteen, or will necessitate a

* *Bulletin No.* 49, American Railway Engineering and Maintenance of Way Association.

night operator at stations where only day operators serve with the lesser number of trains. Wellington* says, of station, terminal, and general expenses: "There is nothing by which they are so quickly affected as by a decided increase in the number of trains."

The writer cannot see why the four fully-loaded trains on the 0.65-per cent grade cannot just about handle the tonnage of six fully-loaded trains on the 1-per cent grade. Supposing the trains to be pulled at 10 miles an hour by the identical engine described on page 5 of the paper entitled "Virtual Grades for Freight Trains," † the caboose to weigh 10.5 tons, the engine and caboose resistance to be 9 lbs. per ton, and the loaded-car resistance to be 5 lbs. per ton, the aggregate gross tonnage of loaded cars carried by the six trains on 1-per cent grades will be 5337, and that by the four trains on 0.65-per cent grades will be 5160. Mr. Beard seems to have overlooked the fact that when the grade is reduced the train load is increased by a larger percentage than is the percentage of grade reduction. As per the data above, the 35-per cent reduction in this case allows an increase of 45 per cent in train load.

The point made by Mr. Beard, however, in regard to the additional cost of reducing the ruling grade due to the slower speeds that heavier trains must make over the road, is well taken, but it seems a trifle ungenerous, under the circumstances, to hold that this will obtain for passenger trains and local freights.

One of the writer's critics contends that his annual cost of the pusher-engine service is too high, and another that it is too low. This is a matter of secondary importance, but the writer has the figures, made three years ago by the general superintendent of a western road, as to the actual cost of such a service where conditions were identical, in almost every respect, coal and water convenient, etc., with those contemplated for the pusher service on this road. The figures were furnished the engineering department of that road for use in calculating the value of a much-needed grade reduction. The annual cost given was $11,056. Further, Mr. Berry, in the bulletin previously referred to, analyzes the cost per mile of pusher-engine service and finds it to be 34.4 per cent of the cost of a train-mile for conditions obtaining on the Union Pacific Railroad. As fuel is very much cheaper near Jellico than on the Union Pacific, this is

* "Economic Theory," Art. 716.

† *Transactions*, Am. Soc. C. E., Vol. L.

certainly a safer percentage on the Louisville and Nashville than in Wyoming. On this basis, the annual cost of this service on this linc would be 34.4 per cent of \$1.08 × 32,544 engine-miles, or \$12,090.

Even when it would have helped him to make his point, in showing that the cost of the pusher service as fixed by the writer was too low, Mr. Beard does not seem to have calculated accurately the annual wages of a double crew, but adopted the writer's figures, which were for a single crew with reasonable allowance for overtime.

Really, Mr. Beard should revise his arithmetic. He should review his geography also, for he seems to suppose that the ore-carrying roads running into Duluth are in Michigan. And Duluth, the Duluth of Proctor Knott, is not a Michigan village.

The writer did not intend any invidious comparison between his own work and that of the unknown engineer who located the Knoxville and Ohio Branch of the Southern. The fact that the road is said to be one of the very best paying divisions of the Southern's system is sufficient to attest the worth of his work.

Neither did he intend to decry the work of the engineer who laid out the Chicago-Kansas City line referred to. The writer is familiar with every foot of the part of the line referred to, and, a few years ago, made some woeful failures in attempting to improve certain parts of this location.

In the comparisons made on grade smoothness, the rise and fall on minor gradients should very probably have been excluded. But since, on the three lines mentioned, so large a proportion of the rise and fall was made on the heavier and longer gradients that the result of the comparison would have been altered but little, the figures which were at hand were used. Each of the lines referred to has a heavier traffic than that immediately in prospect for the new line. The expensive construction necessary on this new line was warranted only because of the fact that the smoothness of the grades gave the owners a road which would admit of comparatively inexpensive operation.

Neither did the writer intend to intimate that any very wonderful engineering work had been done. The only wonderful thing about the matter was that a route, of the nature described, on which a road could be constructed at any outlay that the experienced executive officers of a first-class railway considered reasonable, existed at all in such a country. The writer is quite positive that the final result of the examination and surveys could not reasonably have been antici-

pated from any possible preliminary examination of the country and the available maps. Major R. H. Elliott, former Chief Engineer of the Kansas City, Memphis and Birmingham Railroad, acted as Consulting Engineer for the Louisville and Nashville, in the projection of this whole scheme. He had made a thorough study of the topographic maps, and was probably as familiar with the whole district as any man living. And yet, when the final result of the surveys was communicated to him, his reply was: "That 0.65-per cent compensated grade is astonishing, and I did not know or think it possible."

The conduct of the surveys and examinations was in no wise unusual. The topographic maps rendered unnecessary much of the examination which, otherwise, would have been essential. However, as the maps were somewhat inaccurate, and as the contours on these maps were at 100-foot intervals, and the grade of the railroad so light, comparatively, a good deal of examination was necessary, particularly to determine the character of the country between the contours. The country was too heavily timbered, as a rule, to make much headway in the surveys by stadia methods, which, in suitable country, is a favorite method with the writer. Each party was equipped with aneroids, hand-levels, etc., and the party chief with a saddle-horse. Most of the reconnaissance work was done by the writer, or in conjunction with the chiefs of party. Sunday was a day very much in favor for a horseback ride across country. The writer, on more than one such day, took breakfast, dinner, and supper, each with different location parties, separated by a goodly number of miles. The company was as liberal as could be in regard to the number of men, engineering equipment, and the means for taking care of the men in camp. The writer had all the encouragement and co-operation from his superiors that he could possibly ask for, and was not hampered by any restrictions or requirements whatever. He was simply expected to secure the best line possible under reasonable outlay, and had authority to determine the location, fix the gradients and maximum curves, and to arrange for the letting of the construction contracts.

In conducting such a survey over an extended country, the writer has never believed in the system of having a central office control too minutely the surveys made by a number of parties; nor of hampering the party chiefs by picayunish requirements such as a report at the close of each day as to just how many stations of line have been run out. Such requirements reduce an engineer to a machine, and, by

showing him that he is distrusted, deprive him of that self-confidence, and of the consciousness of the appreciation of his work on the part of his superiors, so essential to the best work. In this day of educated engineers, trained in loyalty as well as in efficiency, men can and always should be secured for such work who can be released from such petty exactions, and with whom it will pay to do it. The writer can recall many a day in survey camps of his own when the best progress was made and not a stake was driven. In such a survey party, it is well that the men who occupy the inferior positions should be engineers *in embryo*, men who have received at least a part of a college engineering course, so that, when rainy days come, or when the party is necessarily held up to work up notes, there will be no idlers in the camp.

Under the conviction that the best place for working out a survey in difficult country is in the camp where the men are doing the work, each party was supplied with a draftsman and drafting equipment, and, instead of requiring a continuous stream of couriers bearing tedious maps, profiles and reports, passing back and forth between the camp and the central office, all such notes were kept in the hands of the chief of party until the survey was completed over the territory he was to cover, when a complete map, profile, estimate and report were made out and submitted by the men who had done the work. The writer believes that the requisite co-operation and unity of purpose between the parties was supplied by his continuous visits to the men in their camps, where he could talk over frankly and fully with each his special problems and difficulties, better than could possibly have been accomplished by any means whatever from a central office miles away from the work. Though the writer's office was in Knoxville, a large percentage of his time, during the location, was spent in the saddle.

Of course, the number of parties that one man can look after in this manner is limited, but it gives the engineer in charge an insight into the character of the work as a whole, which he cannot possibly acquire behind a roll-top desk, or from the most elaborate maps and profiles spread out on a drafting table, miles and miles from the work and the men who are doing it.

It cannot be insisted upon too strenuously that the engineer in charge of such location should not be hampered at the outset (and, as already said, the writer was not) by the usual restrictions as to

grade rates, curve radii, etc. And yet, in order that there may be unity in the results attained by several survey parties, tentative maxima should be fixed, by the engineer in charge, during the preliminary examinations and surveys; and, in order that there may be no careless work in using stiffer grades and curves than those demanded by the country, under the governing financial restrictions, the fact should be constantly kept before the party chiefs that these maxima are only tentative, and that subsequent developments may require the assumed maxima to be considerably reduced.

The line, originally, was reconnoitered between La Follette and Jellico with 1.25-per cent grades in view, and a location through this district was made some seven years ago on this gradient. Surveys with the present construction in view were begun through this district on 1.15-per cent grades in both directions. As already noted, the country was not only reconnoitered, but the original location surveys between Knoxville and La Follette were made on 1-per cent grades in both directions; in each case with the final result which has been described. If Mr. Coverdale would intimate that this is a haphazard method which only just happened to secure good results in this case, the writer differs with him seriously as to the steps necessary to secure successful results in such work.

The writer has never believed in the theory that difficult railway location must needs be done by a genius, or that there are men specially endowed with "an eye for country" to whom such work must always be entrusted. It is work in which training and experience go farther than inspiration, and in which nothing but hard work, common sense, and an intelligent comprehension of the ends in view will enable one to succeed. One cannot be sure that he has gotten the best line for his purposes between any two points in country at all difficult, until he has examined and studied thoroughly the entire area between, and until, in his mind's eye, its traffic possibilities are as clear as the possible revenue from his father's farm, and its outline as well defined as the contour of his mother's yard.

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